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A Call for New ASW Screen Geometries for Carrier Battlegroup Open Ocean Transits Under the 1990's Threat

by

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Submitted in partial fulfillment
of the requirements for the degree

MASTER OF SCIENCE IN APPLIED SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
June 1992

Unclassified
CURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

REPORT SECURITY CLASSIFICATION NCLASSIFIED	1b. RESTRICTIVE MARKINGS
SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
DECLASSIFICATION/DOWNGRADING SCHEDULE	
PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
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NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL
	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO

TITLE (Including Security Classification)
Call for New ASW Screen Geometries for Carrier Battlegroup Open Ocean Transits under the 1990's Threat

PERSONAL AUTHOR(S)
aude F. Martin, III

TYPE OF REPORT	13b. TIME COVERED FROM TO	14. DATE OF REPORT (Year, Month, Day)	15. Page Count
aster's thesis		1992, JUNE	143

SUPPLEMENTAL NOTATION
e views expressed in this thesis are those of the author and do not reflect the official policy or position of the epartment of Defense or the U.S. Government.

COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Anti-submarine Warfare, ASW, ASW Screen, ASW Simulation, ASW Model, Simulation model.

ABSTRACT (Continue on reverse if necessary and identify by block number)

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The author's thoughts are that in the 1990's there will be ever newer, more lethal, unpredictable threats to United State's maritime independence than current doctrine addresses.

The full implementation of the simulation program has not been accomplished. A segment of verification output is shown for expository purposes only. A discussion is given on the adequacy of the model's abstractions along with their possible impact on potential results of experiments.

DISTRIBUTION/AVAILABILTIY OF ABSTRACT	1a. REPORT SECURITY CLASSIFICATION	
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The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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A simulation model was specified. It examines United States Navy Antisubmarine Warfare Screen alternative dispositions for Carrier Battlegroups. The scenario posed is open ocean transit under the threat of an attack from foreign submarine hulls built in the 1990's. The investigation raises the issue of the appropriateness of current Navy practices and suggests that new tactics be developed.

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ACKNOWLEDGEMENTS

I am indebted to the past and present leadership of the Force Warfare Aircraft Test Directorate of the former Naval Air Test Center for the opportunity granted and the confidence shown in my pursuit of graduate education. Specifically, I would like to personally acknowledge Mr. D. Weigel, Mr. B. Russell, Capt. V. Merz (USN Ret.) and Mrs. K. Tyson for their inspiring vision and their unyielding committment to the process of constant improvement.

I have been honored to have Professors P.A.W. Lewis and M.P.Bailey generously and patiently share their time and insights over these past few years. To Professor M.P. Bailey I owe my fond appreciation for showing me the virtues of the profession of Operations Research.

I wish to recognize Mrs. M. Geer for her competence and sense of dedication in the preparation of this document. I would have been lost without her help.

Especially to my wife, Stephanie...thanks.

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I. STUDY CAVEAT

For the sake of completeness, due to the requirements governing this study, topics are presented in this paper which pertain to a full implementation of a simulation analysis. It is in no manner intended, by the discussion of traditional aspects of a simulation analyisis such as measures of effectiveness, experimental design, statistical considerations, or the presentation of sample inputs/outputs, etc., to mislead the reader.

The reader is cautioned that a full implementation of the simulation program specified has NOT been accomplished. Correspondingly, no experiments were conducted and no discussion of ACTUAL results was possible.

II. BACKGROUND

The importance of Antisubmarine Warfare(ASW) to the United States (U.S.) national security seems to shift as challenges posed to maritime capability alternately become blurred by more pressing world events or come strikingly into focus with the introduction of a new technology exploitable by hostile interests.

> ...Technology today permits the development of non-nuclear submarines that can use air-independent propulsion to remain quietly submerged for extended periods without the need for noisy snorkel operations. Combining this type of relatively low-cost submarine with modern cruise missiles, torpedoes and mines results in a formidable Antisubmarine Warfare (ASW) problem during contingency operations in low-intensity conflicts and limited objectives warfare around the globe.... [Ref. 1:Inside Cover]

The author will cite certain credible sources in this section in order to build the context which gave rise to this study. Current U.S. Navy ASW screening tactics seem NOT to have adapted to the changed threat. The U.S. Navy cannot afford new weapons systems merely on the basis of their technological feasibility, nor can it maintain force structure at historical levels to preserve the international status quo. The argument presented here is that new and relevant ASW screening tactics are likely to be the most effective and the least costly means of minimizing submarine threats to U.S. global maritime independence.

> ...I wish our antisubmarine warfare(ASW) forces could see how they look through the periscope. There are strengths (new platforms and new hardware), but there are also weaknesses, misperceptions, and missed opportunities. Operating a submarine against a carrier today is too easy; the carrier's ASW protection often resembles Swiss cheese. Fleet exercises demonstrate this time and again, with the ASW prosecution frequently occuring only after the green

> flares (1) have startled the carriers bridge watch. In short, the bad news is that our ASW is needlessly weak; the good news is that our ASW can be improved...
>
> (1) U.S. Navy submarines fire green flares in exercises when they reach attack positions and have their fire control solutions. [Ref. 2:p. 39]

As far as this author has been able to discern, the current U.S. Navy training doctrine does NOT call for a halt to flight operations even if green flares are landing on the flight deck. The addage 'one fights the way one trains' is applicable here. Not only are ASW screening tactics founded on an out-dated threat, but it seems that submarines are not taken as serious threats by some U.S. Navy carrier commanding officers. Granted maintaining flight proficiency is important, but if combat units are not penalized for exercise mistakes, complacency is likely to PREVAIL.

> ...The goal of scouting is to help get weapons within range and aim them. Scouting gathers information and reports it. The dominant trend in scouting has been the increasing rate of search and the increasing range of reconnaissance, surveillance, and intelligence gathering systems. The reason is obvious; longer-range weapons demand these improvements. Less obvious is the reason scouting has had to struggle to keep up. Weapons fire in any direction...Double the range of an enemy's attack ...and you quadruple the area to be searched. A barrier search-a scouting line-can sometimes cover the perimeter of this expanded area. The bent-line screen invented late in World War II to detect submarines in front of a carrier is an example. Still, tactical commanders cannot be satisfied with a scouting line. For one thing, it is usually pervious: submarines that can approach submerged and launch missiles are a threat that seemingly springs from anywhere at or inside missile range. For another, searches cannot be continuous... [Ref. 3:p. 166]

The threat of a submarine launched missile is not new and can be in the form of a Sea Launched Cruise Missile, a turbojet version similar to a Harpoon , or a missile-boosted torpedo commonly referred to as an ASW Stand Off Weapon. The Soviet and French Navies have had these weapons for some time [Ref. 4:p. 184].

The Soviets have fired close to 700 sea-launched cruise missiles per year since 1986 [Ref. 5:p. 419]. Our own Department of Defense is on record as stating:

> ...The primary threats to the CVBG are...torpedoes and cruise missiles fired from submarines... [Ref. 6:p. 130]

The submarine launching an attack need not develop its firing solution from its own ORGANIC sensors. A former U.S. Naval intelligence officer, Karl Lautenschlager asserts that the most important characteristic of the Soviet Oscar-class submarine is not its great size but the likelihood that its missiles are guided by space-based sensors [Ref. 3:p. 206].

This notion of a missile 'springing from anywhere' is quite alarming even if one is a devout student of the operational art. Deception and surprise are necessary tools in armed deadly conflict [Ref. 7]. If U.S. Navy carrier battlegroup ASW readiness is indeed marginal, then the situation is even further confounded by the introduction of new enemy tactics to coincide with the ferocious lethality of a surprise missile attack.

The following is from a Soviet author:

> ...The range of means of fire, the high speed of approach to the target, and the high probability of destruction (even considering counteraction) determine the tactics of contemporary naval warfare, the sequence of operations by forces, the organization of cooperation, and the time of performance of the combat mission. The adoption of missiles by navies made it possible to significantly increase the range of combat contact. The outcome of the battle now will depend on the capabilities of the weapons, the distance at which target indication is given, and the positional advantage...So surprise in naval wafare plays a decisive role in its outcome. Experience from wars and combat training is a good education for navy men. Unfortunately, when working through missions and during combat practice and drills certain commanding officers do not strive for surprise in action...[Ref.8]

The sinking of the Argentine cruiser, General Belgrano, by a Royal Navy submarine during the Falklands conflict emphasizes the effectiveness of the submarine. The official report reads as follows:

> "211. Our nuclear-powered submarines(SSN) played a crucial role. After the sinking of the General Belgrano the Argentine surface fleet effectively took no further part in the Campaign. The SSN's were flexible and powerful instruments throughout the crisis, posing a ubiquitous threat which the Argentines could neither measure nor oppose. Their speed and independence of support meant that they were the first assets to arrive in the South Atlantic, enabling us to declare the maritime exclusion zone early. They also provided valuable intelligence to our forces in the total exclusion zone." [Ref.9]

Within the last two years, the author has attended ASW courses at the Fleet ASW Training Center, Atlantic, in Norfolk, VA. The bent-line ASW screening tactic for carrier battlegroups was still being taught. The author objected that such a tactic assumes superior speed of the carrier over that of the submarine and only a torpedo threat. When asked what ASW tactics existed for a missile threat, the instructor's response was that a launched missile is an Anti-Air Warfare(AAW) problem. This was disconcerting.

Although this may be the ultimate and most realistic response to the missile threat in the context of the combined warfare commanders, it seems appropriate to task ASW elements with the responsibility of alerting their AAW counterparts in the carrier battlegroup to the time and direction of the impending missile strike. Continued concientious development of this effort to minimize the element of sub-launched missile attack surprise could conceivably lead to better coordination and newer methods of carrier battlegroup defense.

A reference currently in use at the U.S. Naval Academy and at the U.S. Naval Postgraduate School, entitled 'Naval Operations Analysis'[Ref. 10], specifically Chapters 10 and 11 (hereafter referred to as 'text') was the departure point for this study of the ASW screening problem.

This text presents a classic elementary quantitative analysis of the bent-line ASW screening tactic. Figure 1 is from Section 1007 of the text.

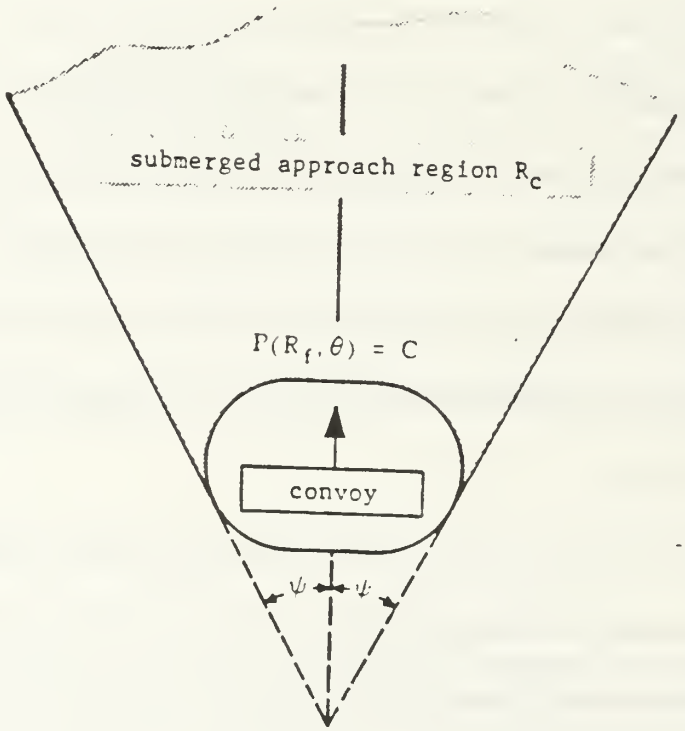


Figure 1. The Submerged Approach Region

In Figure 1 R_c is considered the feasible region for a successful torpedo atack by a submerged submarine. R_f is the range at which the torpedo is fired. $\ominus$ is the angle measued, port or starboard, from the bow of the target ship to the intended relative torpedo track. The probability that a torpedo fired from that point will hit the target, given a firing range and angle on the bow, is $P(R_f, \ominus)$. The boundary between the convoy and the gray submerged approach region is labeled C to denote any arbitary value for a contour representing a locus of points with a constant probability of hit value. Let the submaring speed be α, the formation speed be ß, and the relation of $\alpha < ß$ hold. The submerged approach region is determined by an angle $\psi = \sin^{-1}(\alpha/\beta)$ on either side of the target bow or formation heading. This conceptualization of the ASW screening problem is the one to which this study is directed. The thesis is that this subject needs to be revisited. In all fairness, the text's authors do mention the tactical situation of potential carrier battlegroup vulnerability from 360 degrees in the last sentence.

In the discussion which precedes Section 1007 above, the authors state correctly that in order to maximize ship protection one must minimize the probability of hit from an enemy weapon. The ensuing analysis, however, is built on the following simplifying assumptions: namely,

1. a single submarine engagement (not likely);

2. a single salvo torpedo (i.e. no simultaneous arrivals) that acts like a bullet (i.e. does not have home-on-target characteristics nor does it have a proximity fuse);

3. a carrier speed which is much greater than that of the submarine, to which the following thoughts apply:

> ...In peacetime the wartime advantage of more speed in combatant ships has usually been overrated...Somehow peacetime planners fail to address the tactical problem of a formation being tied to the slowest ship in the force. The effect of damaged units on the speed of the force was and still is often overlooked in peacetime tactical discussions...[Ref.3 p.176]

4. a non-zigzaging or non-changing course (e.g. carriers must turn into the wind to launch and recover aircraft); and, finally,

5. the proscribed bent-line offers no protection just outside the edges(it is hard to believe that a 'zero or one' type of probability of hit exists on either side of this boundary).

The text forthrightly further asserts,

> ...the combination of a pattern running torpedo (or salvo thereof) and a multiplicity of targets is very difficult to evaluate this way... The development and analysis of these more sophisticated models is beyond the scope of this text... [Ref. 10:p. 206]

Given this state of affairs: that the predominant U.S. Navy ASW screening tactic appears outdated and that an analytical approach to the new tactical situation is, for this author, intractable; it was decided to undertake a simulation model and analysis to gain further insight on the problem.

> ...Simulation is essentially a controlled statistical sampling technique(experiment) that is used, in conjunction with a model, to obtain approximate answers for questions about complex, multifactor probabilistic problems. It is most useful when analytical and numerical techniques cannot supply answers.... [Ref. 11: p. 9]

An experiment is taken to mean a series of controlled observations undertaken in an artificial situation, with the deliberate manipulation of some variables, in order to answer one or more questions.

III. PURPOSE

The primary purpose of this study was to specify and code a simulation model with sufficient relevant detail, while retaining an essential conceptual simplicity, so as to allow for an interesting and feasible investigation. The following description expresses this need for balance:

> ...However, the more detail a model includes explicitly, the better we think the model resembles reality. An additional reason for including detail is that it offers increased opportunities for studying system response when a structural relationship within the model is altered for investigative purpose. First, more combinations of structural changes can be considered and, second, more aspects of the response can be studied. On the other hand, detail generally makes solution of problems difficult.... [Ref. 12:p. 3]

Additionally, it was hoped that a completed and verified model might actually be produced by the author and used by other analysts to suggest improvements to the U.S. Navy ASW screening doctrine.

As has been stated, all modules of program code have not been fully implemented. Therefore, only the minimum goals have been acheived as a result of this effort. The following discussion centers on the model specification and a conceptual framework of an experimental design.

IV. SCOPE

A. ASSUMPTIONS AND LIMITATIONS

The following statement from Naval Operations Analysis [Ref. 10] forms the basic assumption upon which this thesis rests:

> ...The placement of the screening units is the primary controllable variable. In other words, the various possible positions of the screening units represent the alternative courses of action that are available to the operational commander when ordering the screen... [Ref. 10:p. 192]

My intention is to broaden the above notion of placement here in this thesis: namely, that the operational commander can manipulate his tactical knowledge of available ASW assets and pertinent environmental conditions and translate it into the postulated zone method adopted in this model. That is, real ASW assets' capabilities are describable, consistent and available for placement such that their composite coverage can be described with approximate accuracy by an enclosed isotropic planar region.

For the sake of simplicity, having no data to indicate otherwise, I assumed from the start that errors involving communications, sensor, or weapon system's accuracy could be statistically uniformly distributed within user-defined ranges. Lifetimes were also to be represented by negative exponential distributions with user-defined means.

In this thesis model of the ASW screening scenario, the environment is sterile and there is no interaction of the players with the environment.

This thesis is UNCLASSIFIED. No attempt was made to interview U.S. Navy personnel to substantiate the need for this study or to describe the behavior of the real system. All information used in the formulation of the problem and the design of the simulation model was obtained soley from the unclassifed references listed at the end of this report.

B. MODEL SCENARIO

1. Carrier's Goals

The scenario posed is of a carrier battlegroup (referred to hereafter as simply, carrier) transiting the open ocean to a specific destination within a specified time constraint. It must arrive on time. This time constraint is referred to here as Speed on Average (SOA). This is the carrier's only mission. The carrier is lethally opposed by a force of high quality enemy submarines whose mission is straightforward: attack, attack, and attack. The opposition is modelled after Soviet platforms due to the EXPORT POTENTIAL of their state-of-the-art weapons technology. This model should not be considered a detection model, but rather, is better characterized as a constrained engagement model.

2. Model World

The world is represented by a rectangular Cartesian plane. The carrier's motion is considered always to the right or up throughout the algorithmic schemes in this model. It starts in the lower left corner and heads in a variable manner towards the upper right hand corner. Figure 2 below provides a conceptualization of the gaming area.

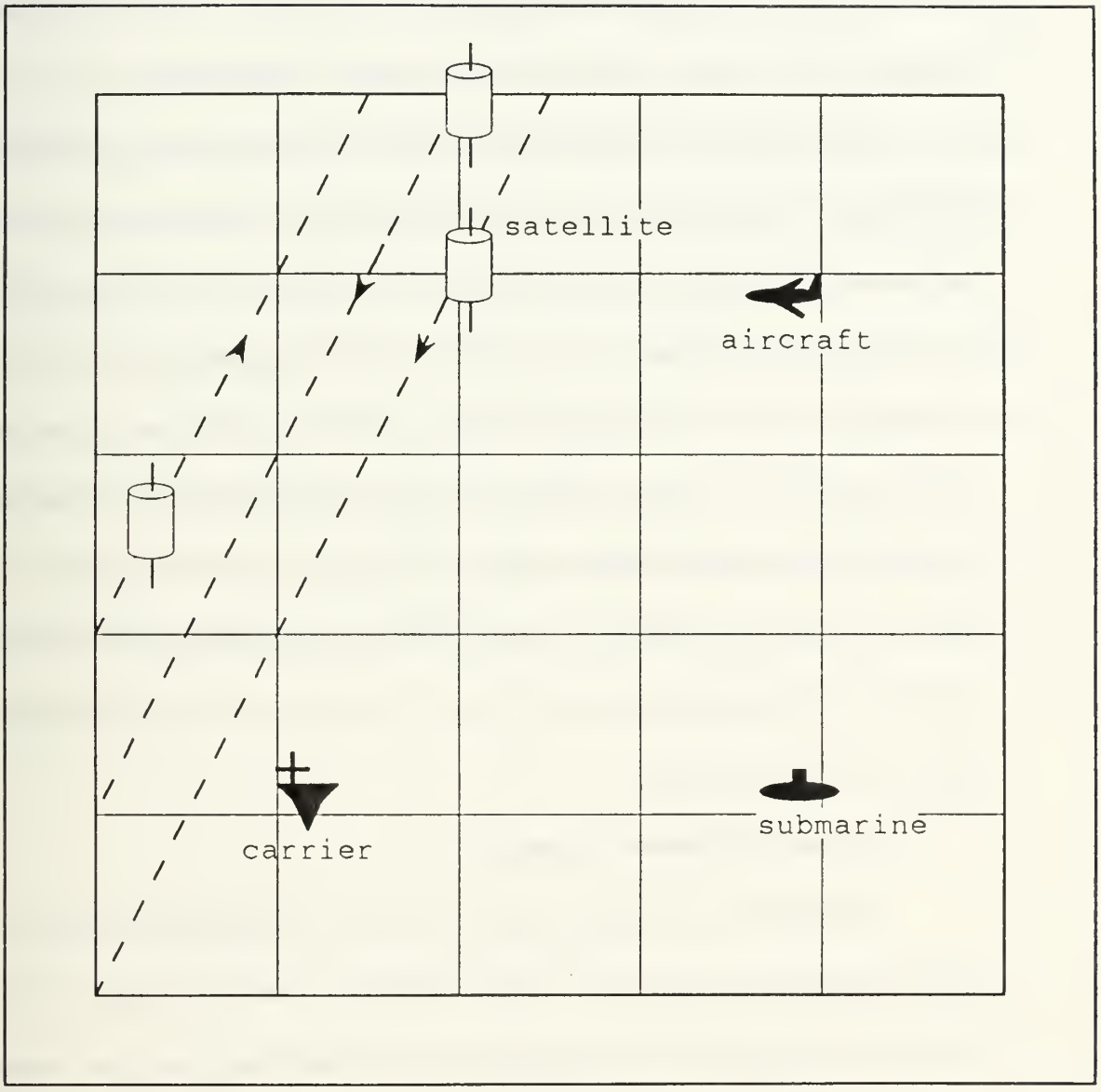


Figure 2. The Model World and Players

3. Players

The U.S. complement of players also includes two types of reconnaissance platforms: a fixed-wing Air ASW platform and a low-earth orbiting satellite. These reconnaissance platforms are for detection of the opposition only.

The enemy is composed of four types of submarines (Oscar, Akula, Sierra, and Kilo), a fixed-wing long range aircraft and a low-earth orbiting satellite. The reconnaissance platforms are for detection of the opposition only. The submarines are armed with missiles and torpedoes. These weapons are carried on the submarines. There is a total of five weapon types. There are three types of missiles: a Sea Launched Cruise Missle; a turbojet-driven projectile similar to a Harpoon; and, a missile-boosted torpedo commonly referred to as an ASW Stand Off Weapon. There are two types of torpedoes: a standard size 533 mm diameter equivalent to the U.S. Navy 21 inch diameter MK-48's; and a large size 650 mm diameter for which there is no U.S. equivalent.

4. Carrier Self-Defense Construct

A key idea in this model is that of the carrier's polygons of influence, which are both offensive and defensive. This simplifying method was employed to manage the carrier's many ASW and AAW resources and their complex independent extensions by translating them into areas of simple, specific functionality. These areas are referred to as Zones one through five, each with its own unique features. These are described below.

The carrier forms the intersection of twelve radii, each separated by an angle of 30 degrees. There are five sets of colinear radii (of possible varying length) each labeled one through twelve. These are arranged precisely like a standard clock face starting with number twelve assigned the same slope as the carrier's course. This orientation is constant about the carrier's slope. Each set defines a unique isotropic zone of weapon system capability. The zones are numbered one through five, from inside to outside. Zone 1, then, is the carrier itself; Zone 2 represents that area covered by the carrier's AAW guns; Zone 3 is that area covered by surface-to-air missiles; Zone 4 is that area that represents the ASW screen; and, Zone 5 is that area which is controlled by the carrier's aircraft.

Figure 3 below represents the model's implementation of the bent-line U.S. Navy ASW screen; that is, a forward looking one similar to that shown in Figure 1 Chapter II.

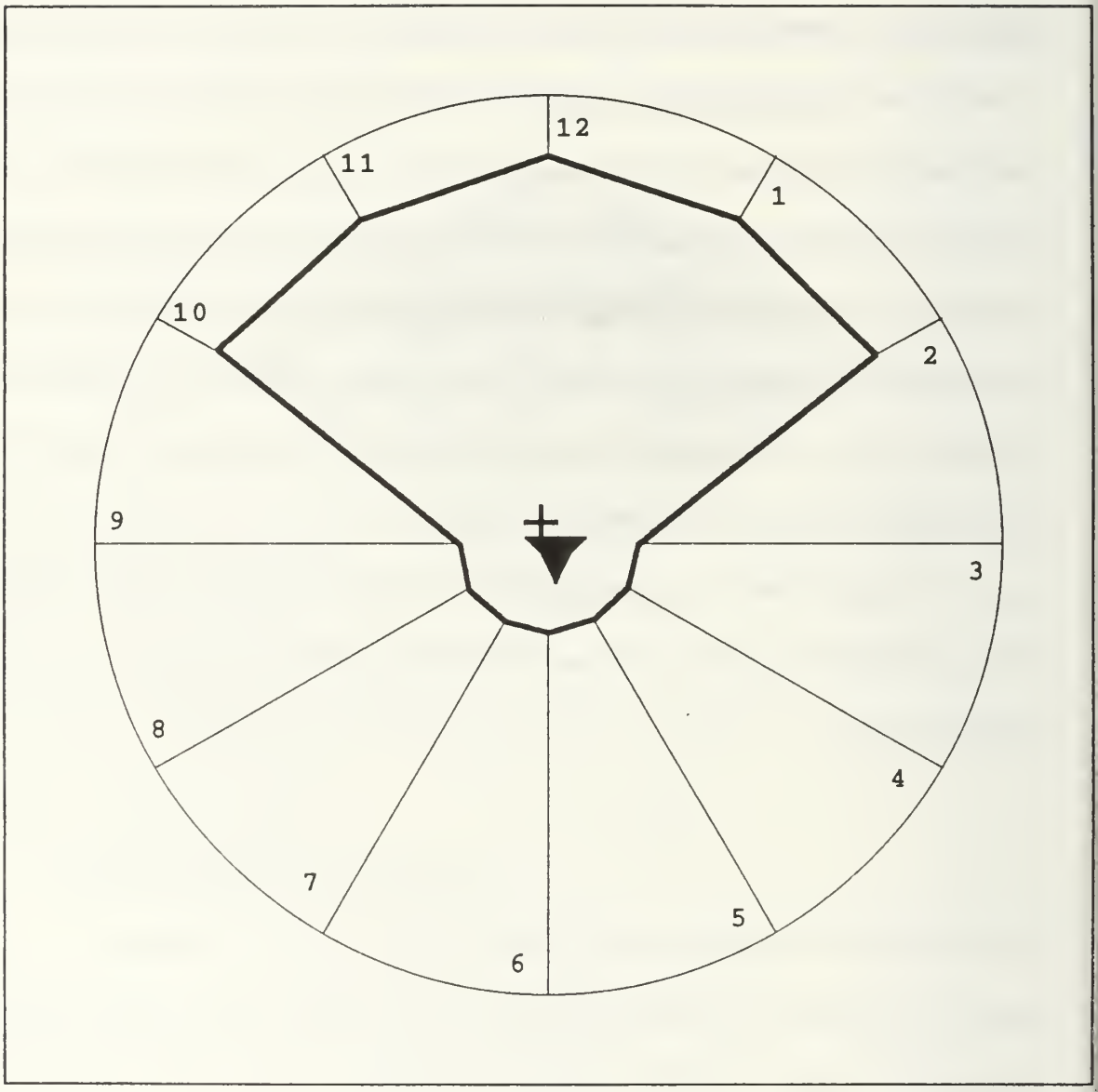


Figure 3. An Example Carrier Zone 4 (ASW)

The following pages intentionally and simply display a sequence of Figures 4 through 10 which illustrate the basic concepts and relations in this scenario. These same figures are repeated in Chapter V and accompanied there with a detailed discussion. This sequential presentation is meant to help the reader visualize the basic workings of the model prior to the specific discussion of the underlying model algorithms.

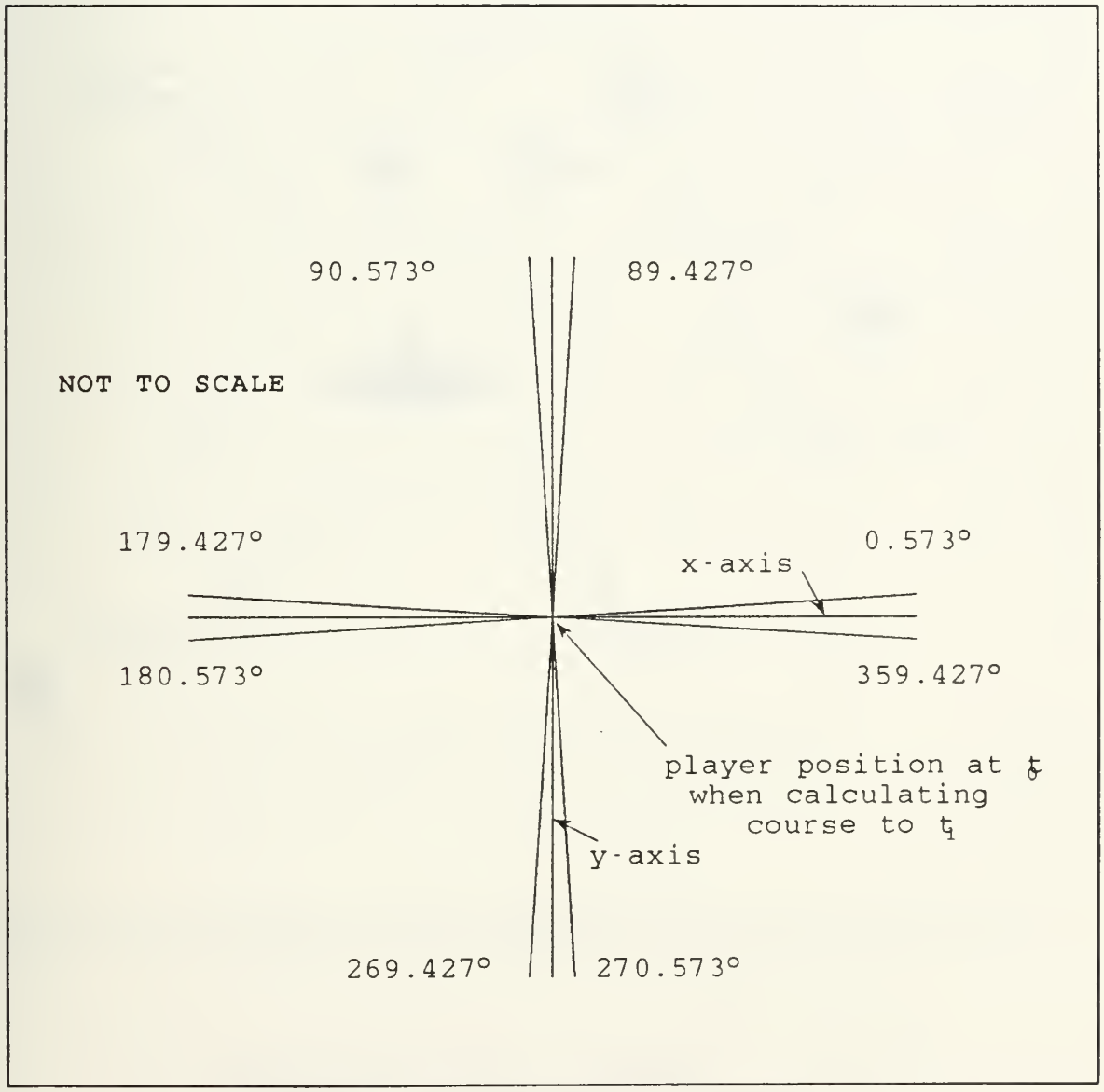


Figure 4. Legal Courses for all Platforms

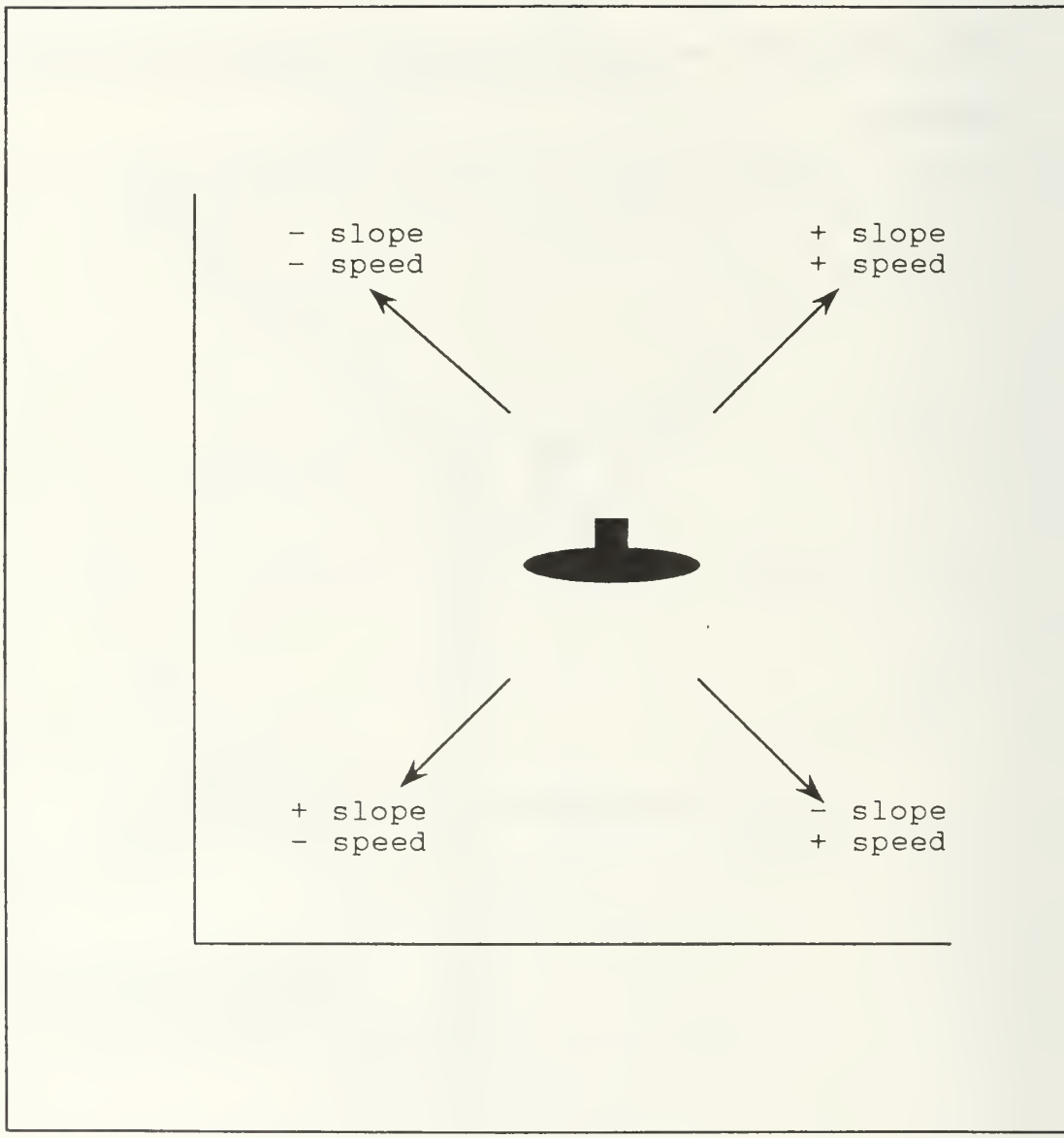


Figure 5. A Depiction of Mobility

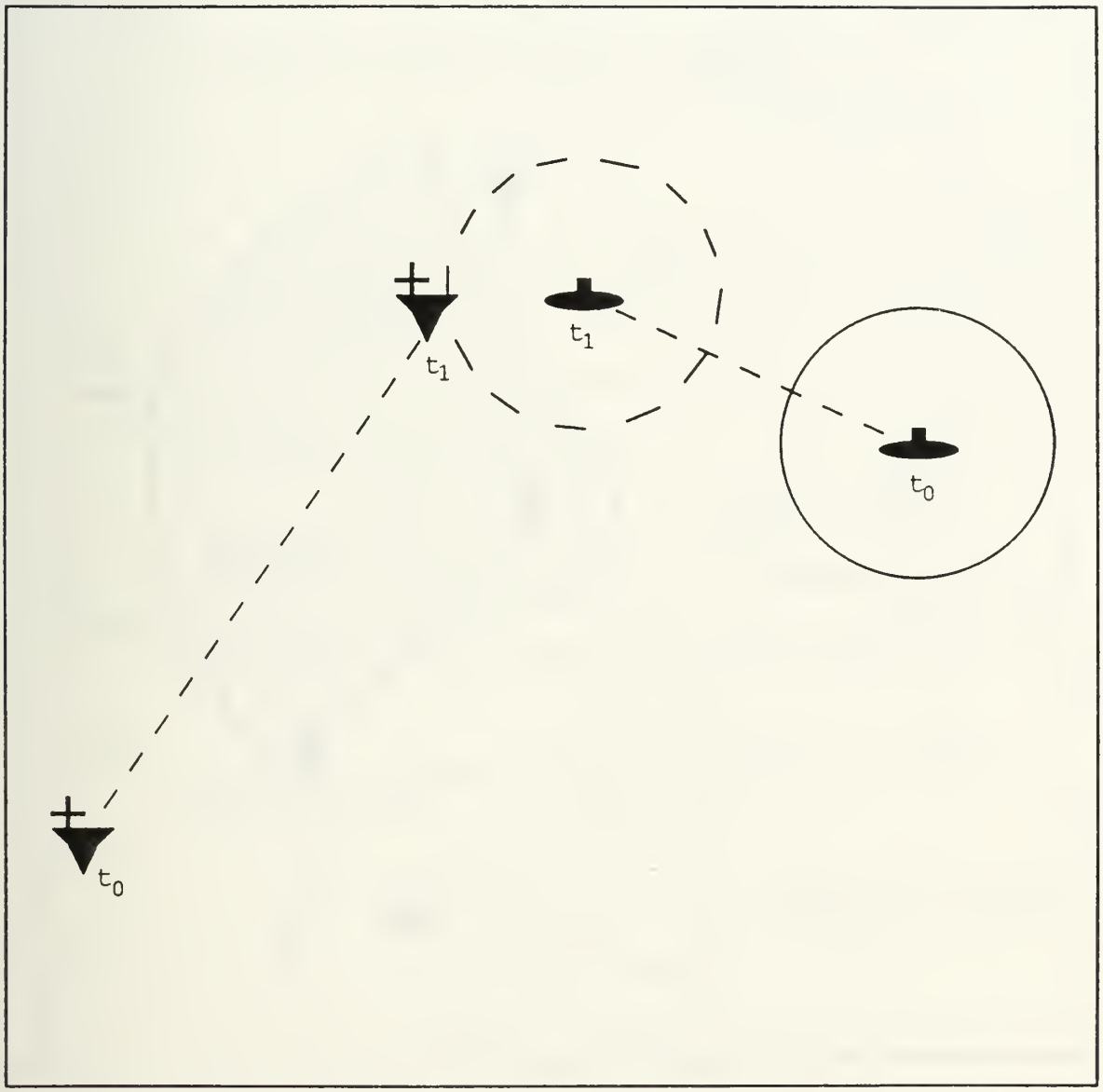


Figure 6. An Illustration of a Detection

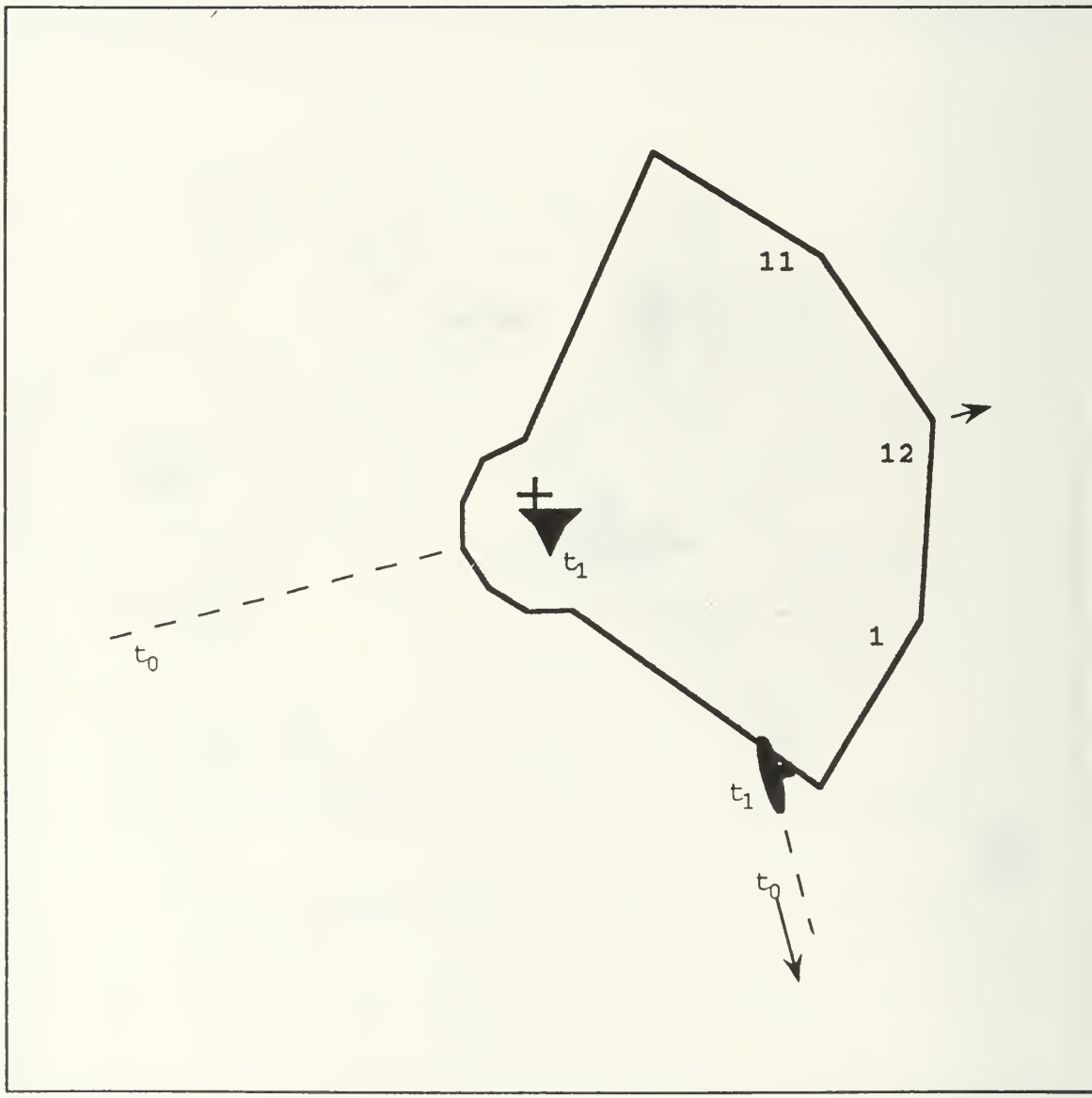
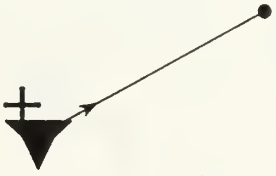


Figure 7. An Illustration of a Penetration

collocation: carrier (X,Y) = object(X,Y)

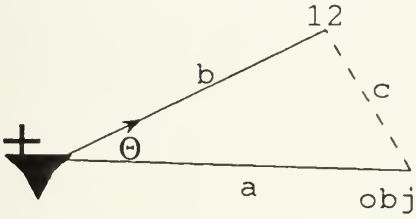
collinearity with carrier's slope:



distance ≤ zone radius

collinear with other radius or between two radii:

step 1:
find object's relative bearing to carrier's slopes



LAW OF COSINES

$$\cos\Theta = \frac{c^2 - a^2 - b^2}{-2ab}$$

$$\Theta = \arccos(\cos\Theta)$$

step 2:
divide Θ by 30° to determine radius or radii of interest

step 3:
determine objects relative position within or without a zone

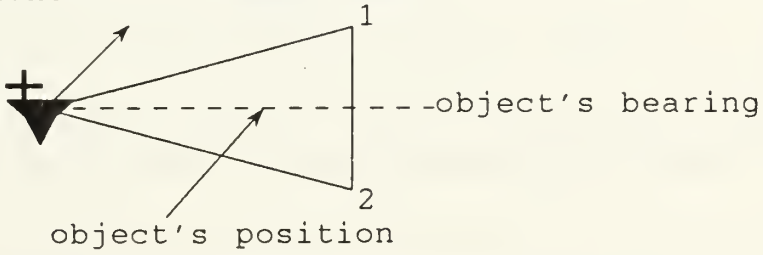


Figure 8. Within-zone Penetration Considerations

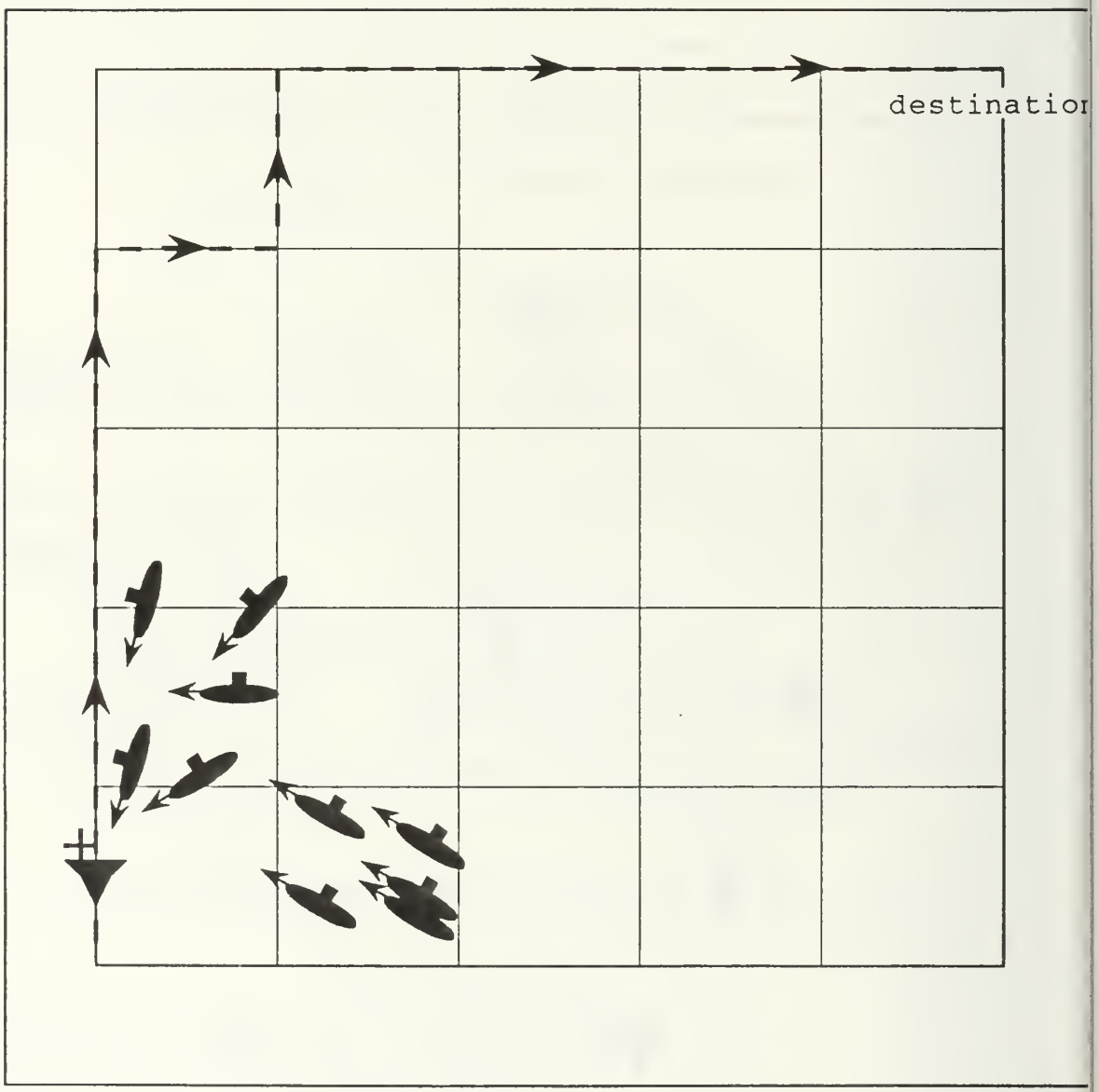


Figure 9. An Illustration of Carrier Evasion PIM

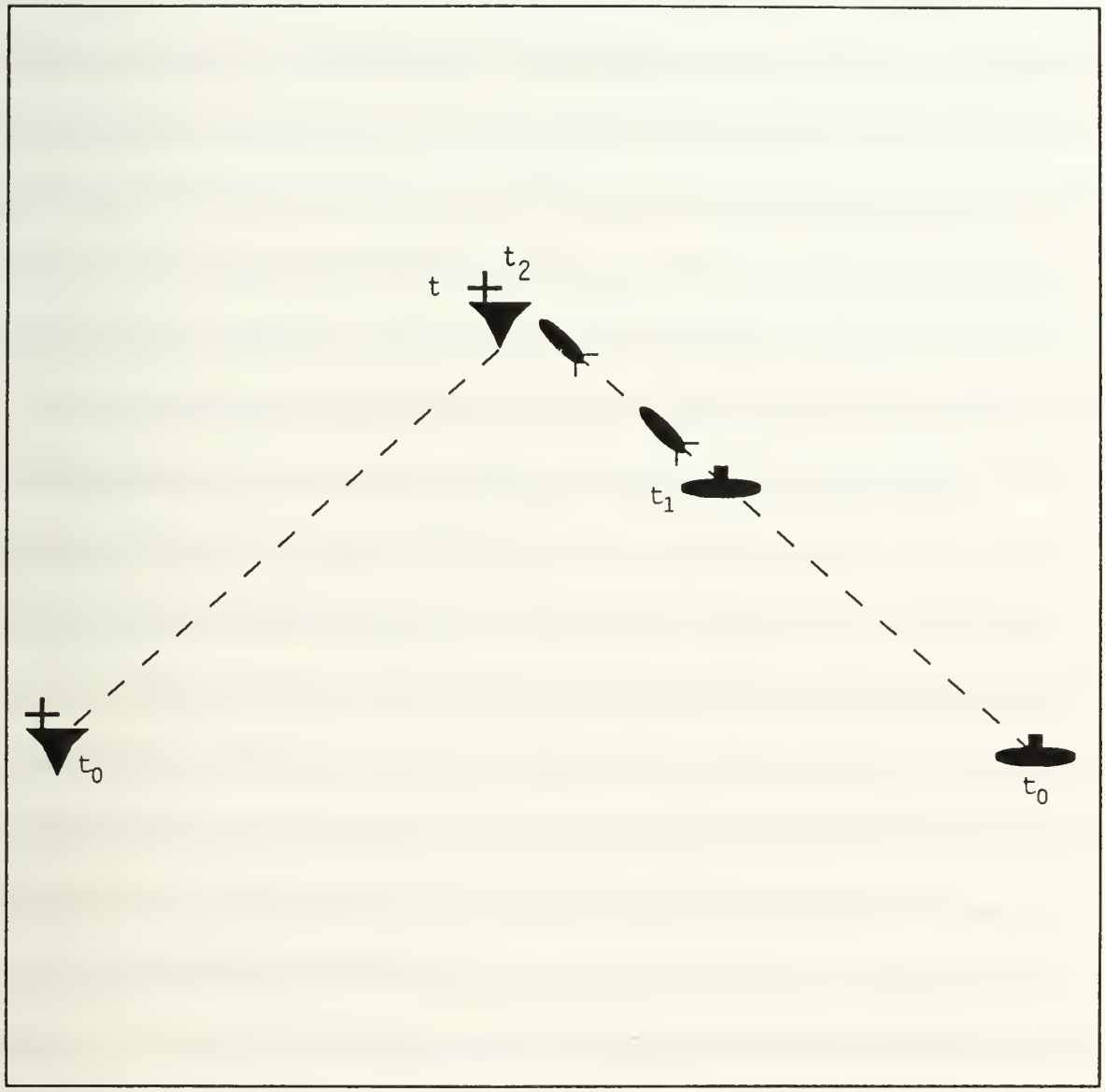


Figure 10. Submarine Attack-Weapon Launch

5. States of Knowledge

New information concerning the opposition's order of battle, for each side respectively, is the essential condition which causes significant activity to occur in the model. New information comes about in the form of a detection of the opposition. Two types of detections, acoustic and electro-magnetic, are possible. A Monte Carlo approach is used to decide if a detection should occur given the fact that the detection range criteria has been met. This simulates the randomness associated with environmental conditons, skill of the crew, functioning of equipment, etc.

The carrier's zone structure simplifies the examination of the placement of the carrier's many ASW assets by allowing the study to focus on the essential characteristic of zone shape. (A discussion of the potential impact on the simulation analysis validity as a result of modelling abstractions made in this study is given in Chapter VI.) The modelled zones represent only those capabilities contained within the carrier battlegroup. Thus, initial detections of potentially hostile foreign objects are usually accomplished via assets outside of the carrier battlegroup. The carrier's activity against a penetrating object is usually cued by these outside assets. The carrier relies on outside information to be relayed to it via the reconnaissance aircraft or satellites. If any player on a given side makes a detection, that information is broadcast to a network scoreboard of all players on that respective side. The submarines themselves along with their air and space assets can make detections of the carrier. The same broadcast method applies to their operation.

6. Carrier Movement

The movement of the carrier is described below (refer to Figure 9 above). Upon receipt of new information concerning the opposition, the carrier's remaining area of possible movement is overlayed with a rectangular grid. The nodes of this grid are assigned a weight. This weight corresponds to the sum of weights representing the weapon capabilities of those weapons able to reach that node at the precise future time the carrier could traverse that node. This, from the carriers current position and at the carriers current speed. The carrier selects a course which minimizes the sum of the node weights. The carrier's chosen course is referred to as a Plan of Intended Movement (PIM).

7. Submarine Movement

The submarines, upon receipt of new information, are given courses and speeds which intercept the carrier based on that side's knowledge of the carrier's latest reported PIM. The submarines' on-board weapons loads are factored into this plan of attack calculation and all launch points and times are set.

8. Reconnaissance Movement

Only the carrier and submarines respond or react to new information by changes in course and speed. Aircraft have been given a user-defined PIM and they expire at its conclusion. Satellites continually appear in the area and then disappear to reappear at regular intervals to mimic low-earth type orbits. Satellites have a full-scenario-long lifespan.

9. Order of Battle

There is only one carrier. Each side has the maximum of five aircraft and satellites each. There is a maximum of ten submarines: two OSCAR's; two AKULA's; two SIERRA's; and four KILO's.

Each submarine can carry each of the five type of weapons. ALL submarines are programmed to attack immediately and with their maximum range weapon. They do this successively and relentlessly. If magazines are depleted, each is programmed to approach the carrier to occupy its attention to simulate a cooperative engagement where assigned players draw the risk of fire in order to optimize the chances of success of a coordinated attack by non-targeted forces. Their are no provisions for an underway replenishment of the submarine weapons stores. A provision for a weapon reliability error is included along with the capacity for a multiple weapon launch from a single submarine.

10. Carrier Self Defense Operation

Enemy submarines, aircraft, and weapons get absorbed by the carrier polygons of influence simulating the action of individual Battlegroup assets. If detected by the carrier's assets, a Monte Carlo technique is employed to determine if the penetrating entity may pass undamaged through a Zone. If this does not yield safe passage, a random draw is taken from an exponential distribution with a weapon-specific mean; a lifespan is then assigned to the inbound object.

The ability of the carrier to defeat the given inbound object is treated as a function of two independent states. These can be seen as the carrier's attention span

or saturation quotient, and the carrier's readiness state due to battle damage. A user-defined cumulative distribution function is assigned to represent the required associated probabilties for each of these states.

11. Scenario Summary

In summary, the model was specfied so as to focus on the ASW screening problem. As an engagement model, it is simplistic. The submarine is the only platform which fires weapons. There are no surface ships. There are no aircraft with weapons. Only two classes of objects, the carrier and submarines, react to each other. The carrier seeks to evade the submarines and the submarines single-mindedly seek to engage the carrier. Every decision rule for player behavior is aimed at saturating the carrier with maximum activity and distraction. This was done to determine the significance of the ASW screen shape in an experimentally efficient manner and to analyze the behavior of ASW screen shape under worst-case, dense scenarios.

V. METHODOLOGY

A. MODELLING APPROACH

The approach taken in formulating and executing this model was focused on the notion that the critical junctures in the unfolding of the scenario of the carrier crossing the open seas could be captured in discrete moments in time. This way of visualizing the sequence of actions requires many simplifications of the real world.

Other concepts that require simplification concern the many subtlties and variances in the environment, in the operation of equipment and machines, and in the human interaction with both. Errors involving communications, sensor, or weapon system's accuracy were assumed to be uniformly distributed within user-defined ranges. Lifetimes were assumed to be represented by negative exponential distributions with user-defined means.

The method used for the latter is the randomization process called the Monte Carlo method. This is a well known technique that employs a uniform probability distribution, U(0,1), and a sufficient number of replications to reliably estimate critical values for problems that are typically analytically intractable.

It is used here in the determination of a detection, a penetration, a survival of a penetration, a successful weapon's launch, and the carrier's ability to defeat an incoming weapon or hostile submarine or aircraft. A correct value for probabilities associated with this method underpins the validity of any analysis of a serious, real

nature. This study never intended to use real data. This study PURPOSEFULLY contains no real data on the performance envelope's of any objects and correspondingly all probabilties that would have been used were merely assumed plausible.

The time between events is taken to be somewhat uninteresting in this scenario. This is not too unlike the real world where steaming underway to a destination is routine and not marked by any critical events so long as one's information about the world remains unchanged.

Carriers certainly are engaged in many concurrent, vital and complex activities underway but, for this study, the essential activity is dealing with a life-or-death threat posed by an enemy submarine. In order for either side to effectively move about they need too see where they are going and who or what of interest is in the way. The carrier must critically rely on outside assets for information on pending threats. This dependence in the model does indeed mimic the real situation to the extent that the battlegroup's own organic assets rarely make uncued detections of submarines. They need some starting information from national surveillance assets.

All other players' actions and exchanges have been assumed away for the purposes of concentrating the study on the minimum components of movement, detecting the opposition, attacking the carrier, and defending against attack. This effectively synopsizes the real world ASW situation in a war.

Events are the critical junctures in the real world. The very name implies something significant. Events have the same meaning in this model. Based on a

change in the state of something defined to be of interest in the scenario, either the carrier or a submarine choses to react and change its activity. Events imply decision. An effort was made to keep events relatively pure; free from anything not strictly policy related. Therefore, it was determined that the bulk of calculations necessary to the model's operation would be executed elsewhere. In other words, separate routines do the more intensive calculations.

Throughout Chapter V references to SIMSCRIPT II.5 coding conventions will be done in a stylized fashion. Discrete event simulation receives some brief comments. Events and Routines are described in an algorithmic manner.

1. Scheduling Events

SIMSCRIPT II.5 offers both an Event and a Process approach simulation environment. The central issues which guide a decision between the two alternatives are the nature of the activities in the real system and the sequenced execution of those activities in simulated time. An event is seen as an instantaneous change of state of the system. A process is a group of related events that are separated in time and therefore a process consumes time. An event-driven approach was chosen for this study due to its conceptual simplicity.

The following provides a fundamental explanation of this type of an approach:

> ...Discrete event simulation concerns the modelling of a system as it evolves over time by a representation in which the state variables change only at a countable number of points in time. These points in time are the ones at which an event occurs, where an event is defined to be an instantaneous occurrence which may change the state of the system...Historically, two principal approaches have been suggested for advancing the simulation clock, namely,

> next-event time advance and fixed-increment time advance...With the next-event time advance approach, the simulation clock is initialized to zero and the times of occurence of future events determined. The simulation clock is then advanced to the time of occurence of the most imminent (first) of these future events, at which point the state of the system is updated to account for the fact that an event has occured and our knowledge of the times of occurence of future events is also updated. Then the simulation clock is advanced to the time of the (new) most imminent event, the state of the system is updated, and future event times are determined, etc. This process of advancing the simulation clock from one event time to another is continued until eventually some prescribed stopping condition is satisfied...for a discrete-event simulation model, periods of inactivity in a system are skipped over by jumping the clock from event time to event time...It should be noted that the successive jumps of the simulation clock are generally variable (unequal) in size....[Ref. 13:p. 5]

The majority of the work conducted behind the scenes in this simulation model's execution was housed in the routines which calculated the next most imminent events.

2. Unscheduling Events

Absolutely critical to the design philosophy of this model, is the fact that certain state changes will definitely invalidate the conditions which predicated the scheduling of some future events. All future events are kept on the event calendar. Therefore, it was required to construct methods to unschedule particular classes of events (remove them from the event calendar) in order to proceed to calculate a new next most imminent event based on the new state.

B. MODEL STRUCTURE

The reader should note that there is not intended to be a one-to-one correspondence here between the Subsection titles used for events and routines and the actual names or groupings used in the SIMSCRIPT II.5 program code. The

names used here are meant to be self-explanatory and are not as cryptic as those found in the program code. This was done to enhance the flow of the discussion.

A basic design decision was made to handle the bulk of the calculations necessary to the operation of the model outside of the events. It seemed sound software engineering practice to keep the events free of any non-state-related information. In other words, a routine should do calculations and the proper function an event was to make essential system decisions based on the results of those calculations.

Therefore, an examination of the list of events reveals the author's analysis of those state changes which were pivotal to the operation of the system being studied. Inspection of the list of routines shows those mathematical operations which represent the essential physical activities of the players in the simulation.

1. Events

The information about the behavior of the real participants in the scenario under study is what is modellled in an event. In the strictest sense, no decisions are made in the running of the program. Every action is a result of the analysts' prior decisions. Keeping this in mind, the discussion will continue to speak as if the players were real entities playing out their roles.

Events are where the significant behavior of the system occurs. In the following sections, a description of the state and the information which is weighed in the choice of alternatives for each player is provided. Each section begins with a Table which shows on the left, the variable names used to convey critical

information to an event and, on the right, whether this information is stored in a global variable or an entity attribute; with the entity attribute listed. For the most part, only information as to the identity of the players is imported into applicable events. This allows other pertinent information to be indexed and accessed through entity attributes and specific arrays.

a. Course & Speed Changes

Table 1 Course and Speed Changes

every CV_WAY_PT	
has a CV_WPT_FROM_TIME	Global Variable
and a CV_WPT_FROM_PLACE	Global Variable
every LS_WAY_PT	
has a LS_WPT_HULLNO	LS.HULL.NO
every RC_WAY_PT	
has a RC_WPT_HULLNO	RC.HULL.NO

Immediately upon entry into any event the EVALUATE Routine is called in order to update all player positions.

All objects in motion except satellites and inbound weapons eventually change their direction. In addition, submarines and the carrier change their speeds too. If either side does not receive any new information on the opposition, and enough simulation time has elapsed, a WAY_PT event occurs. One is always scheduled for every object except an inbound weapon. A launched weapon in this

simulation goes in a straight line towards the fix the submarine predicts. Satellites are constrained to cross the game board at an approximate 60 degree angle to the x-axis at equidistant horizontal spacings.

A check is made in WAY-PT for any opposition players that may be tracking the subject platform about to change direction and/or speed. If any opposing player is in contact with the subject platform, then several of the future events scheduled for those tracking players need to be unscheduled and new sets rescheduled based on the subject platform's change in state.

A check is also made in this event for any opposition players that may be scheduled to penetrate a carrier zone. Only in the instance that this event is focused on the carrier will any penetrations be unscheduled. The carrier zones are sort of AMOEBA-LIKE MASSES absorbing everything in their path. The carrier is surrounded by five overlapping zones which act as defensive and offensive mechanisms simultaneously. These zones travel with the carrier and maintain their orientation. The absorption capability of a given zone is a function of the number of simultaneous targets it must track (attention span) and its readiness (battle damage). Attention span is a scarce but renewable resource. When the carrier changes course, the predicted placement of these zones is likely to be invalidated. This future location of a zone is necessary to predict future zone entries. If a PENETRATION is scheduled for a submarine, it may need to be unscheduled if the carrier changes course and/or speed in order to preserve overall scenario validity. However, an opposing aircraft whose PIM is non-adapting may incur an attention span cost due

to a scheduled PENETRATION occurring, when in fact, even though a zone would no longer be penetrated, one should not. This is like knowing a threat is out there lurking but having no idea where. This type of concern over pending threats justifiably consumes attention span in the real world.

It is important to note that in the case of a released weapon, a penetration is never unscheduled. This allows for two possibilities. One where a penetration occurs when in fact one should not. And two, a zone entry may occur with the possibility of going unnoticed, and thus, unpenalized. This is explained by the fact that weapons in this simulation once aimed are never recalled nor their tracking adjusted mid-course. The cost to attention span is justified by the fact that any detected inbound weapon, on course or not, reasonably consumes attention span. The next case is where a carrier change in course causes an inbound weapon to leak through. Here, it would previously have passed the carrier's zones by but now will not. The author views this as a justifible consequence or penalty due to an unfortunate placement of appropriate carrier battlegroup assets. This treatment is a positive bias towards the disastrous effects of surprise due to poor scouting. That is, the author is favoring his very thesis, that lack of proper ASW screening can have disastrous consequences.

b. Detection of Opposition

This event is central to the operation of the scenario. It is THE CONDITION from which new information develops. The NEXT DETECTION routines schedule this event to occur at precisely that instant in time when the Seeing

Table 2. Detection of Opposition

EVENT ATTRIBUTES	ENTITY ATTRIBUTES
every CV_DETECTION	
has a CV_DET_MODE	Global Variable
and a CV_DET_SEER_CLASS	CV.CLASS
and a CV_DET_SEER_HULLNO	CV.HULL.NO
every LS_DETECTION	
has a LS_DET_MODE	Global Variable
and a LS_DET_SEER_HULLNO	RC.HULL.NO
and a LS_DET_SEEN_HULLNO	LS.HULL.NO

platform is within range of the Seen platform. An acoustic detection usually takes place at significantly shorter ranges than an electromagnetic detection. Type of detection is referred to as MODE of detection in the simulation. MODE information is passed to the event along with the identity of the SEER and the SEEN. Next, user-defined values are input to a uniform probability distribution function whose output is assigned as a time period required before this detection information may be used by a given team. This serves as a proxy for errors in the sensing equipment or in the communication networks of the particular detecting side. Given this lagged time, a BROADCAST event is scheduled. A broadcast will NOT take place until some time in the future. The message it conveys is only approximately true for current simulation time. This makes each side's information inaccurate by construction. The limits of this inaccuracy are strongly influenced by the lag time limits which is preset by the user.

c. Broadcast to Network

Table 3 Broadcast to Network

EVENT ATTRIBUTES	ENTITY ATTRIBUTES
every CV_INFO_TO_LS	
has a CV_BRD_TIME_SEEN	CV.SCBD.TIME
and a CV_BRD_X	CV.SCBD.X
and a CV_BRD_Y	CV.SCBD.Y
and a CV_BRD_COURSE	CV.SCBD.SLOPE
and a CV_BRD_SPEED	CV.SCBD.SPEED
every LS_INFO_TO_CV	
has a LS_BRD_TIME_SEEN	LS.SCBD.TIME
and a LS_BRD_HULLNO	LS.HULL.NO
and a LS_BRD_X	LS.SCBD.X
and a LS_BRD_Y	LS.SCBD.Y
and a LS_BRD_COURSE	LS.SCBD.SLOPE
and a LS_BRD_SPEED	LS.SCBD.SPEED

What makes BROADCAST interesting is that it effects significant changes in the states of the simulation. A wealth of event unscheduling/scheduling can occur prompted by this event. Information is finally made available to the objects themselves as well as to their team members. The TIME of the sighting, the identity of the SEEN, its POSITION, COURSE, and SPEED are all there for inspection. These are posted on that team's scoreboard, if the information is more recent (TIME of original detection is later in simulation time) than that which is posted. Given this system, it is possible that stale yet more accurate information may be discarded in preference for information with a fresher time tag. Thus, if the arriving information

passes a newness test, then action is taken to unschedule existing applicable events and appropriate routines are invoked to calculate the next most imminent events.

d. Contact Loss on Opposition

Table 4 Contact Loss on Opposition

EVENT ATTRIBUTES	ENTITY ATTRIBUTES
every CV_LOSE_CONTACT	
has a CV_LCT_MODE	Global Variable
and a CV_LCT_SEER_CLASS	CV.CLASS
and a CV_LCT_SEER_HULLNO	CV.HULL.NO
every LS_LOSE_CONTACT	
has a LS_LCT_MODE	Global Variable
and a LS_LCT_SEER_HULLNO	RC.HULL.NO
and a LS_LCT_SEEN_HULLNO	LS.HULL.NO

This event is simple in that it resets a seen flag which says that the particular player in question has now moved out of detection range. This fact, however, is nontrivial when routines are invoked for the carrier's movement. The carrier's movement is focused on a path of minimum danger. The algorithm only counts those submarines which have their SEEN flag set. More specifically, if no platform on a given side has contact on an opposing player, then that opposing player can maneuver unhindered until such time as it is re-acquired by the opposition. Therefore, the loss of contact may give an opponent significant tactical advantage.

e. Penetration of Carrier Zone

Table 5 Penetration of Carrier Zone

EVENT ATTRIBUTES	ENTITY ATTRIBUTES
every LS_PENETRATION	
has a LS_PEN_HULLNO	LS.HULL.NO
and a LS_PEN_ZONE	Global Variables
every RC_PENETRATION	
has a RC_PEN_HULLNO	RC.HULL.NO
and a RC_PEN_ZONE	Global Variables
every IW_PENETRATION	
has a IW_PEN_CLASS	IW.CLASS
and a IW_PEN_HULLNO	IW.HULL.NO
and a IW_PEN_ZONE	Global Variables

In keeping with the design goal that events remain relatively pure policy mechanisms, the event PENETRATION itself merely adds a weight for the penetrating entity to account for the additonal consumption of the carrier's attention span. The event PENETRATION calls a routine known as SURVIVAL. SURVIVAL uses the information on the carrier's attention span and its battle damage (readiness) state as an input to a Monte Carlo routine which decides if the penetrating object is defeated for a particular zone.

If a submarine penetrates Zone 1, the carrier itself, it is considered an immediate stopping condition. The game is ended and summary statistics and data generated and, if programmed, the next replication is initialized and run.

f. Submarine Weapon Launch

Table 6 Submarine Weapon Launch

EVENT ATTRIBUTES	ENTITY ATTRIBUTES
every LS_LAUNCH_IW	
has a LS_LIW_WEAPON	Global Variables
and a LS_LIW_HULLNO	LS.HULL.NO

This event executes the command to launch a submarine's current maximum range weapon. A Monte Carlo technique is used given a user-defined value to test for any potential reliability problem with the weapon. This weapon is targeted at a position in future time. Namely, the carrier's course is extrapolated a distance compiled by applying its current speed to the time it takes the weapon to travel a percentage of its maximum range. This projection uses the carrier scoreboard position and course and speed to find this targeting solution or intersection. This scoreboard position varies from the actual carrier position due to the aforementioned constructed inaccuracy and randomness of platform and detection node time lags.

g. Removal of Opposition Object

Table 7 Removal of Oppostion Object

EVENT ATTRIBUTES	ENTITY ATTRIBUTES
every LS_REMOVE	
has a LS_REM_HULLNO	LS.HULL.NO
and a LS_REM_FROM_TIME	Global Variables
every RC_REMOVE	
has a RC_REM_HULLNO	RC.HULL.NO
and a RC_REM_FROM_TIME	Global Variables
and a RC_REM_FROM_PLACE	Global Variables
and a RC_REM_FROM_ZONE	Global Variables
every IW_REMOVE	
has a IW_REM_CLASS	IW.CLASS
and a IW_REM_HULLNO	IW.HULL.NO
and a IW_REM_FROM_TIME	Global Variables
and a IW_REM_FROM_PLACE	Global Variables
and a IW_REM_FROM_ZONE	Global Variables

REMOVAL is an event which pertains to objects other than the carrier. A removal is the result of a lifespan expiration. This may occur due to an unsuccessful penetration of a carrier zone or from a user-defined time limitation.

If a submarine, or an opposition aircraft, penetrates a Zone other than 1, and a removal is determined, the action taken is twofold. First, the carrier's attention span is replenished by the amount previously consumed by the object's presence. Second, the object's in-play flag is set to zero and it is subsequently ignored for the

rest of the replication. (NOTE: The carrier's inventory of readiness is non replenishable. Battle damage or readiness cannot increase since no provision is made for underway repairs. Zeroing out of this quantity is a simulation stopping condition.

The removal of an inbound weapon is similar. In addition, the proximity of the weapon's hit position to that of the carrier is calculated. The reader is reminded that the weapon was aimed at a predicted carrier position based on a scoreboard estimated position with the potential of being significantly different than the carrier's actual position. This distance is then compared with that of the particular weapon's lethal radius for either a direct or near hit. If either such condition is met, the carrier's battle damage state is adjusted. Battle damage cannot be repaired or replenished during a given simulation replication. If the capacity of the carrier to sustain weapons hits is totally exhausted, a stopping condition is met. The replication is ended and summary statistics and data generated, and,if programmed, the next replication is initialized and run.

h. Arrival of Reconnaissance

Table 8 Arrival of Reconnaissance

EVENT ATTRIBUTES	ENTITY ATTRIBUTES
every RC_START	
has a RC_RCS_HULLNO	RC.HULL.NO

Reconnaissance vehicles, aircraft and satellites, enter the game board in this event. Satellites have regular orbits. They cycle on in this event and they cycle off in the WAY_PY event. These vehicles arrive at preset user-defined times. They also have a preset user-defined PIM. They have user-defined starting positions. Aircraft starting positions may also be determined by providing user-defined inputs to a uniform distribution function whose output is the desired position. A provision is also made for aircraft starting positions to correlate with an object on the same team.

i. Carrier Replenishment

Table 9 Carrier Replenishment

EVENT ATTRIBUTES	ENTITY ATTRIBUTES
every CV_UNREP has None	None

In order to launch aircraft or to periodically take on a replenishment of supplies, the carrier MUST slow to a speed of approximately five to seven knots. This particular event sets the carrier's speed to its minimum value for a specified time period. It schedules itself at regular intervals. Both the duration and frequency of this period are user-defined.

j. Carrier Arrival at Destination

Table 10 Carrier Arrival at Destination

EVENT ATTRIBUTES	ENTITY ATTRIBUTES
every CV_SOA has None	None

This event is called CV_SOA and signals the SUCCESSFUL arrival of the carrier to its user-defined destination. This implies: timeliness; that no submarines have penetrated to Zone 1; and, that insufficient battle damage was incurred to have stopped the replication hereto. The replication is here ended and summary statistics and data generated, and, if programmed, the next replication is initialized and run.

2. Routines

The purpose of a routine in this model is to be an engine of calculation. All activity is interrelated through mathematical expressions. Values for speed, course, detection range, zone shape and extension, probabilties associated with detection, penetration, survival of a penetration and weapon's launch, and the carrier's ability to defeat an incoming weapon or hostile submarine or aircraft, all fuel this engine. The primary output of each major routine is the value TIME. Time is the mechanism by which the scenario advances from one interesting state to another. Due to the

architecture of constancy of values for all attributes and parameters between events, and the nature of linear motion, a specific value for time implies the ability to project specific future positions for all objects in the scenario. Therefore, the determination of the next most imminent event is, in this implementation, reliable by construction.

The presentation of algorithmic notions and their subsequent formulation and solution as equations is presented in the ensuing discussion. Only initial formulations and their final derivations will be shown. Discussion of mechanical details will be generally avoided. The mathematical sophistication of any method does not exceed that of elementary algebra and plane trigonometry.

a. Movement

Entities are treated as point masses with constant speeds and linear courses. Changes in courses and speeds occur instantaneously. This ignores the concept of inertia and thus allows objects to go from a stopped position to a constant velocity in no time. It also allows for immediate and abrupt reversals in course. The model world is a standard Cartesian plane with all of the attendant conventions this implies. Upon every occurance of an event the positions of each player are updated by the EVALUATE routine. Equation Set 1 provided below illustrates the method of updating each in-play object's X and Y coordinates. The time increment since the last evaluation is recorded and updated at each instance of this routine's execution as it is essential to this operation.

position at time t, is

$$t_1 = (X_{t_1}, Y_{t_1})$$

such that:

$$X_{t_1} = X_{t_o} + (speed \; x \cos(\arctan(slope))) \; x \; (t_1 - t_o)$$
$$Y_{t_1} = y_{t_o} + (speed \; x \sin(\arctan(slope))) \; x \; (t_1 - t_o)$$

where:

t_o = time of last evaluation

t_1 = current time

X = X-axis coordinate

Y = Y-axis coordinate

Equation Set 1. X and Y Coordinates Update

The repetitive operations such as calculating an object's course, the distance between two objects, and movement of the endpoints (X and Y positions) of the carrier radii were facilitated by writing standardized Functions. Equation Sets 2, 3, & 4 below illustrate the operation of each of these functions respectively.

$$slope = \frac{Y_{t_1} - Y_{t_o}}{X_{t_1} - X_{t_o}}$$

where:

t_o = time of last evaluation

t_1 = current time

X = X-axis coordinate

Y = Y-axis coordinate

Equation Set 2. Slope Function

The Slope Function contains checks against errors introduced from division by zero either within this routine or for other operations which use the output of this routine. The repeat of Figure 4 below shows the effect of these checks as constraints on the legal ranges of values for platform courses. Shaded regions are where slopes are between [100,-100] around the y-axis and between [.01, -.01] around the x-axis. A slope of 100 or -100 was arbitrarily chosen as sufficiently vertical for this model and avoids this discontinuity of the tanget function. A slope of .01 was arbitrarily chosen for a horizontal slope to avvoid division be zero in some instances. These values yeild the odd degrees shown blow in Figure 4. These shaded regions (not drawn to scale) are gaps only in the sense that they limit the direction an object may take from its present position. This does NOT imply that gaps exist in the model world itself. Since the carrier's course is always up and to the right and there is no strictly vertical or horizontal movement, problems with certain trigonometric functions' behavior are avoided (such as with the tangent and arctangent restrictions).

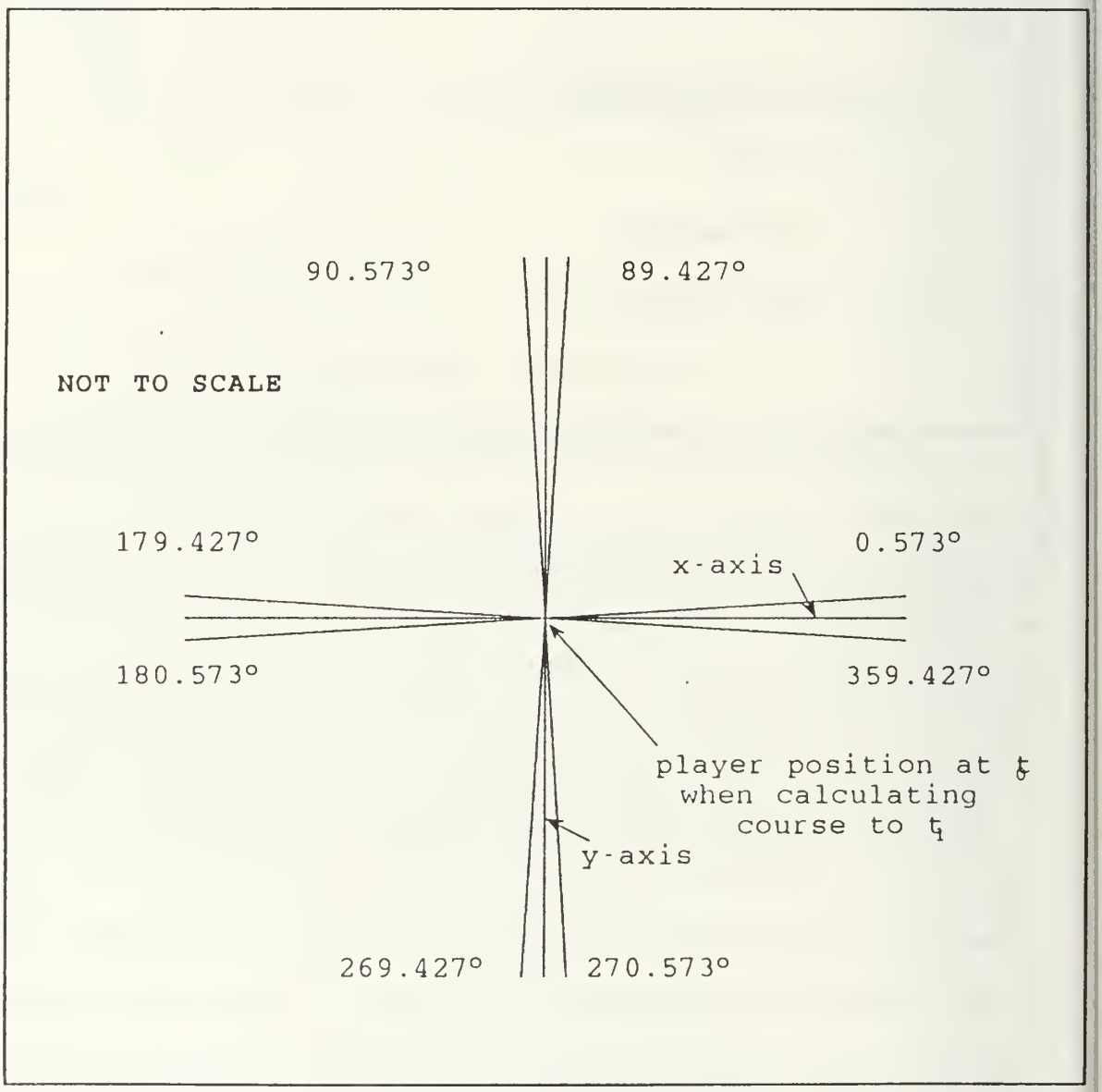


Figure 4. Legal Courses for All Platforms

The Distance Function employs the Pythagorean Theorem. Distance here is usually the length of the hypoteneuse which is equal to the square root of the sum of the square of the lengths of the two remaining sides. These lengths are coveniently the differences in magnitude of each object's X and Y coordinates respectively. Equation Set 3 below shows this relationship.

$$distance = \sqrt{(X_1-X_2)^2 + (Y_1-Y_2)^2}$$

where:

X_1, Y_1 = position of object #1

X_2, Y_2 = position of object #2

Equation Set 3. Distance Function

The Radii Endpoint Movement Function was constructed specifically to suit the SIMSCRIPT II.5 trigonometric function implementation scheme. It is trivial. Equation Set 4 is included below for completeness.

$$input = \frac{(\arctan(\text{carrier slope}) - \text{radius angle to carrier slope})}{\text{radians}}$$

where:

input is used for cosine and sine functions in Equation Set 1.

Equation Set 4. Radii Endpoint Movement Function

Directionality is a function of both the sign of an object's speed and its slope. A positive speed always means motion is to the right, and, conversely, a negative speed means motion is to the left. Motion up (+) or down (-) is determined by the sign of the product of the speed and slope. The repeat of Figure 5 below depicts this.

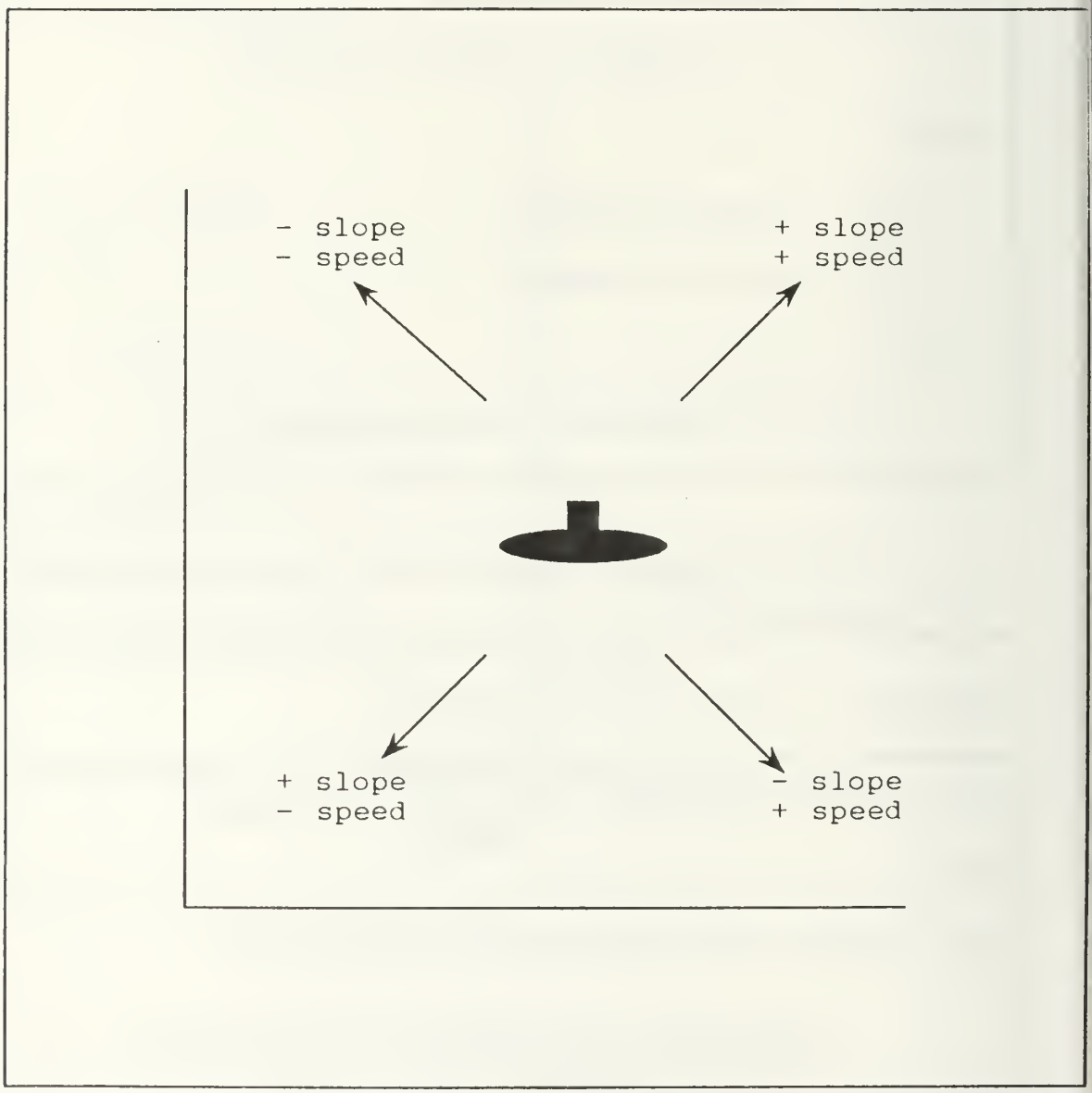


Figure 5. A Depiction of Mobility

b. Next Detection

The routine Next Detection determines which object on the game board will next produce a detection of some object on the opposing side. It determines the DETECTOR, the DETECTEE, and the TIME of the detection. Since a given detection may ultimately alter the course or speed of some object only the very next detection is sought and scheduled by the routine. This minimizes the number of events which may need to be unscheduled.

This routine is pivotal. Both the carrier and the submarine desire to know of each other's whereabouts. The carrier would prefer to avoid the submarines. The submarines desire to approach the carrier to within range of their weapons. The reconnaissance aircraft and satellites sole function is to search and report any information on the enemy.

An object's constant speed and direction project its location in a straight line into future simulation time. Location is one of the primary variables in the scenario under study. Information on the opposition is mainly about their location. Given that direction and speed are constant between events, the calculation of points in future time is straightforward. The repeat of Figure 6 is provided to visualize a typical orientation of players expected to precede a detection.

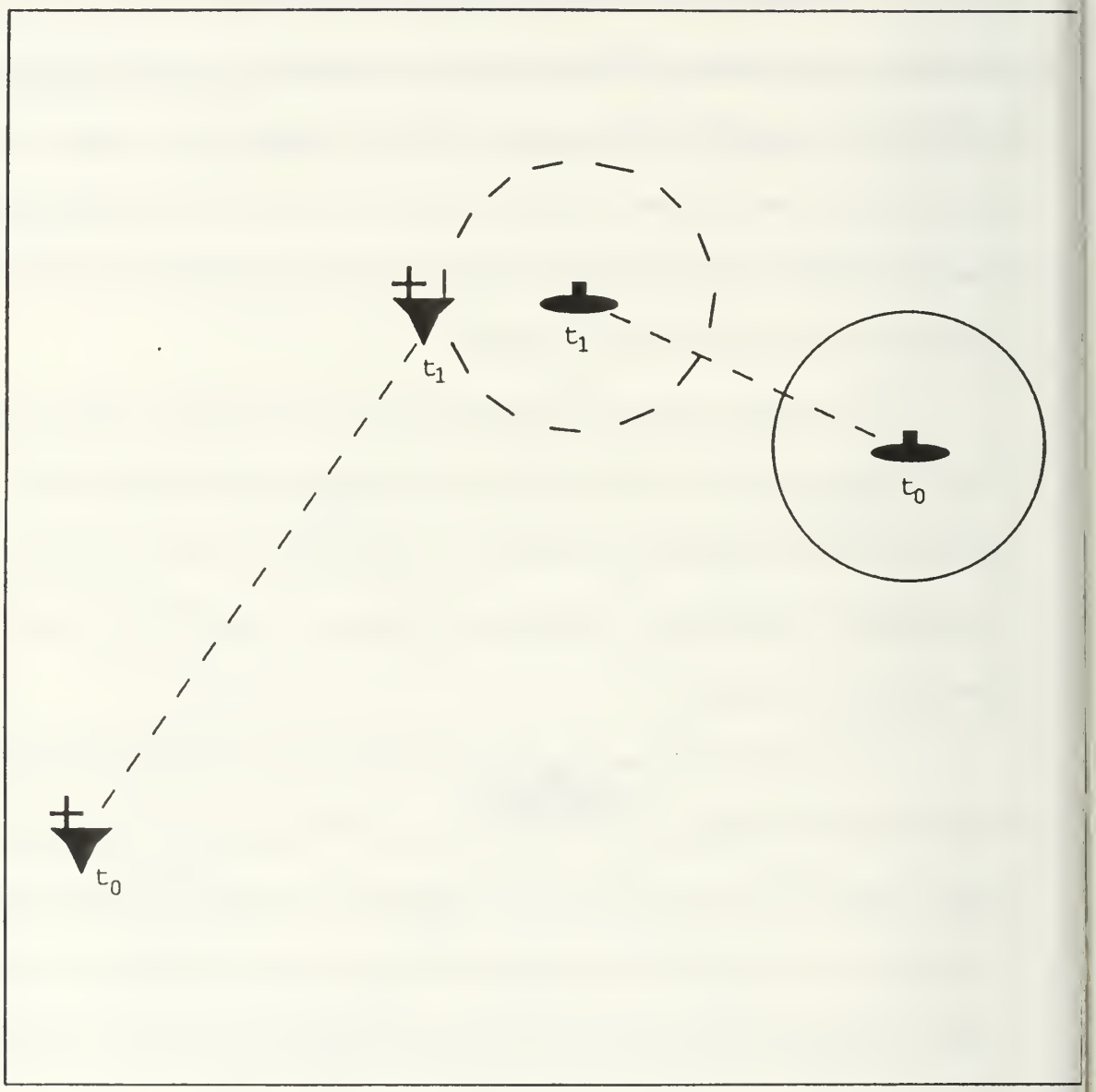


Figure 6. An Illustration of a Detection

Quadratic expressions are employed to solve for the required time of intersection of the DETECTEE object and the DETECTOR's circular envelope of sight (range, is in effect, the radius of a circle centered on the detecting object). Equation Set 5 is given below to demonstrate the algebraic interpretation of the notion of a next detection shown in Figure 6.

Solving for required time, the discriminant was tested for a positive value and the resulting roots were examined for applicabilty. A discriminant having the value of zero was determined to be a tangential situation where a DETECTION and a LOSS OF CONTACT occurred simultaneously and was therefore declared uninteresting.

Given two real roots, several types of situations could be pending. In the case where they both equal zero, it was determined that both objects must occupy the same position and have the same course and speed. This is not prohibited but is considered a degenerate case. Another degenerate case arises when both the roots are negative. This is explained as those points in past simulation time when a detection would have occured along with its complementary loss of contact. A combination of a positive root and a negative root determine that a detection has already occured and that a loss of contact has yet to occur. Two positive roots imply

to find: a time t in the future such that two objects, A and B, will be separated by an exact detect distance r.

Future positions:

$$X_{A_t} = X_{A_o} + [\cos(\arctan(slope_A)\ x\ (speed_A)]\ x\ t$$
$$Y_{A_t} = Y_{A_o} + [\sin(\arctan(slope_A)\ x\ (speed_A)]\ x\ t$$
$$X_{B_t} = X_{B_o} + [\cos(\arctan(slope_B)\ x\ (speed_B)]\ x\ t$$
$$Y_{B_t} = X_{B_o} + [\sin(\arctan(slope_B)\ x\ (speed_B)]\ x\ t$$

each of the above bracketed expressions is assigned the variable names α, β, γ, δ, respectively, for ease of discussion

detect distance r:

$$r = \sqrt{(X_{A_t} - X_{B_t})^2 + (Y_{A_t} - Y_{B_t})^2}$$

A generalized Quadratic expression was derived for t, using the standard coefficients Q, R, and S.

$$Qt^2 + Rt^2 + S=O$$

and the solution for t is given by:

$$t = \frac{-R \pm \sqrt{R^2 - 4QS}}{2Q}$$

where:

$$Q = [(\alpha-\gamma)^2 + (\beta-\delta)^2]$$
$$R = 2\ [(\alpha-\gamma)\ (X_{A_o}-X_{B_o}) + (B-\delta)\ (Y_{A_o}-Y_{B_o})]$$
$$S = [X_{A_o} - X_{B_o}]^2 + [Y_{A_o} - Y_{B_o}]^2 - r^2$$

Equation Set 5. Next Detection Algorithm.

that both events have yet to occur. The minimum root is chosen to schedule the next detection and the maximum root the next loss of contact.

A simplifying assumption made here was that in the time between a DETECTION and a LOSS OF CONTACT, the various phases of ASW prosecution known as localization, classification and tracking were occuring with complete efficiency. No attempt was made to account for human-in-the-loop type of interactions such as Recognition Differential or the fact that knowledge gained from having tracked the opposition might introduce asymmetry in the conditions under which contact would be lost; a detection arising from an unalerted state being qualitatively different than the loss of a weak signal in an alerted state.

c. Next Penetration

The routine Next Penetration determines which object on the game board will next pierce an applicable zone of the carrier. It examines each enemy aircraft, detected submarine, and launched weapon. It determines which of these objects will enter a zone the carrier has constructed to defeat it. The next PENETRATOR, ZONE and TIME of the penetration are all calculated and a Penetration Event is scheduled. At that time, an assesment of the carrier's attention span and battle damage will be given to the routine Survival to determine if the incoming object may continue.

The carrier is surrounded by five overlapping zones which act as defensive and offensive mechanism's simultaneously. These zones travel with the carrier and maintain their orientation. Many types of varied and irregular shapes are possible to

construct since the radii length are user defined. The carrier may or may not be the centroid of a given zone. Zero radii lengths may actually put the carrier on the boundary of a given zone. The repeat of Figure 7 below is shown for further clarification.

The Event PENETRATION occurs only if the carrier KNOWS that a foreign object has come within one of its five zones. If a submarine is undetected, then it may actually move into the carrier's polygon's of influence without any action being taken. The only aircraft which cause zone action are the enemy's. All weapons are considered detected along with the launching platform when a weapon is released. Any entry of an object, detected or undetected, into Zone 1 causes that object to be automatically terminated. If that object is a submarine, it is a stopping condition for that particular replication.

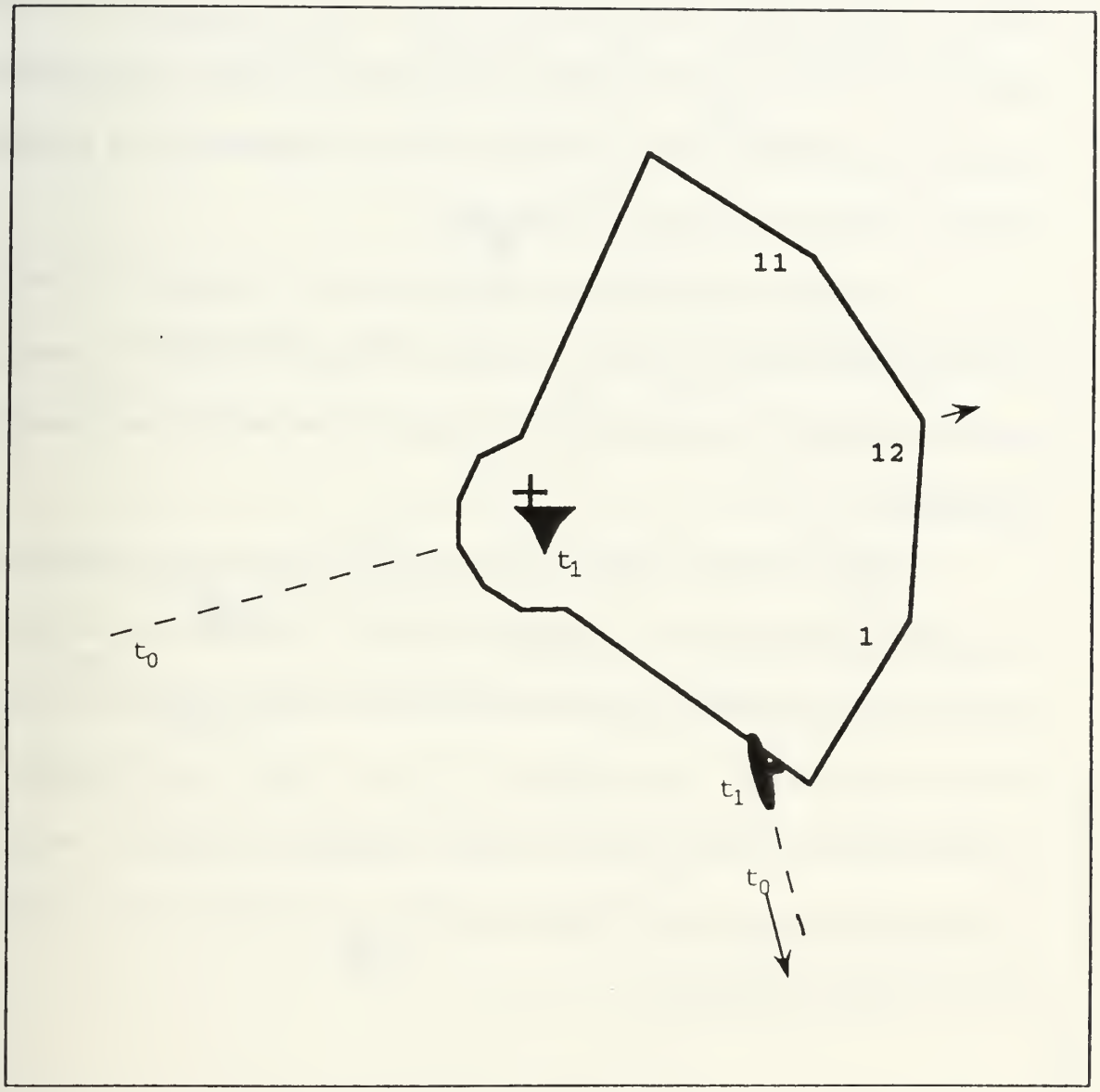


Figure 7. An Illustration of a Penetration

Penetrations can take place from within a zone as well as from without. Starting positions, or a previously undetected submarine, can induce the condition where an object suddenly appears already inside a zone. (This requires a different treatment than that of predicting when a penetration is to occur. The situation to be checked is whether or not an object, at the very beginning of its replication lifespan, is detected and inside any given zone.)

A weapon only really comes into being once it is launched. Therefore, it cannot be detected until this time. The repeat of Figure 8 is offered in conjunction with Equation Set 6 to help depict the steps of the within-zone penetration calculations.

This notion of an object's first appearance occuring already within a zone is treated in some detail here. If a given object is not collocated with the carrier or collinear with the carrier's slope, then it must lie on the line collinear with another radius or lie between the extensions of a pair of radii. Tests for position as collocation with the carrier involve the simple comparison of X and Y coordinates. Tests for position with respect to objects in the direct path of the carrier are straightforward distance comparisons.

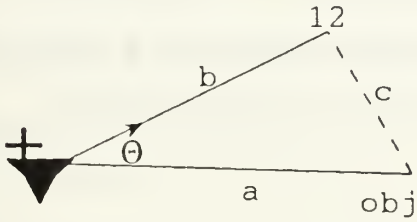
collocation: carrier (X,Y) = object(X,Y)

collinearity with carrier's slope:

distance ≤ zone radius

collinear with other radius or between two radii:

step 1:
find object's relative bearing to carrier's slopes



LAW OF COSINES

$$\cos\Theta = \frac{c^2 - a^2 - b^2}{-2ab}$$

$$\Theta = \arccos(\cos\Theta)$$

step 2:
divide Θ by 30° to determine radius or radii of interest

step 3:
determine objects relative position within or without a zone

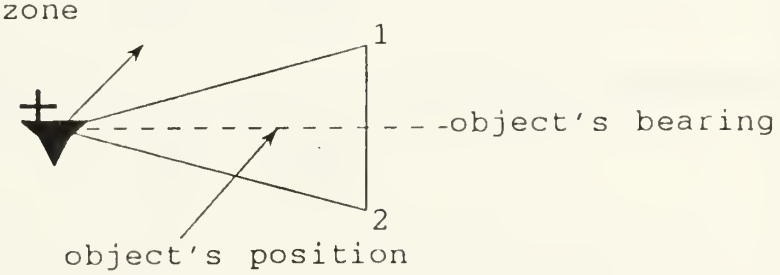


Figure 8. Within-Zone Penetration Considerations

Tests for the object's bearing require several steps. This can occur at the beginning of a given replication or at the beginning of object's lifespan. First, a relative bearing to the carrier's course is determined using the carrier's position, the position of an endpoint of radius twelve for an arbitrary non-zero Zone and the position of the given object. These three points form a triangle. The Law of Cosines is then invoked to find the relative bearing. The object's relative position with respect to a given Zone (tested from inside out) is found using the point of intersection of the carrier/object line and the radii endpoints line. The distance of the object to the carrier is then compared to distance of the point of intersection to the carrier since that point is either a zone vertex or on a zone boundary. Equation Set 6 below shows the derivations used to determine this point of intersection.

test for object location with respect to carrier

1. Collocation
2. Collinear with carrier's slope
3. on a given radius or between two radii

    a. compute Θ using LAW OF COSINES

    b. test relative location of object with respect to each zone

        i. calculate point of intersection of line between carrier and object and line between appropriate radii end points

        ii. test if distance from object to carrier is less than or equal the distance from this point to carrier.

Step 3.a. is illustrated in Figure 8 step 1.

Step 3.b.i. is illustrated in Figure 8 step 3 and described here:

slope of object-carrier line = slope of intersection point-carrier line

$$\frac{Y_o - Y_c}{X_o - X_c} = \frac{Y_p - Y_c}{X_p - X_c}$$

slope of radii endpoint line = slope of intersection point-radius endpoint line

$$\frac{Y_1 - Y_2}{X_1 - X_2} = \frac{Y_p - Y_1}{X_p - X_1}$$

$$let\ \alpha = \frac{Y_o - Y_c}{X_o - X_c} \qquad let\ \gamma = \frac{Y_1 - Y_2}{X_1 - X_2}\ \ (known\ quantities)$$

Equation Set 6. From-Within Next Penetration
(continued on next page)

$$\therefore \quad Y_p = \gamma \times (X_p - X_1) + Y_1$$

$$let \quad Y_p = \beta \quad (substitution; assignment)$$

$$Let \quad \alpha = \frac{\beta - Y_c}{X_p - X_c}$$

$$\therefore \quad X_p = \frac{(\alpha \times X_c) + Y_1 - (\gamma \times X_1) - Y_c}{\alpha - \gamma}$$

$$NOTE: \quad (\alpha - \gamma) \quad cannot = 0$$

where

endpoint radii = (X_1, Y_1) and (X_2, Y_2)

carrier position = (X_c, Y_c)

object position = (X_o, Y_o)

point of intersection = (X_p, Y_p)

Equation Set 6. From-Within Next Penetration

The typical situation encountered here is the determination of that point in future simulation time when the object's future location will intersect with an edge or vertex of an applicable carrier polygon. Figure 7 illustrates the typical scenario of a from-without penetration and Equation Set 7 below shows the applicable calculations.

The method used to predict a from-without PENETRATION Event involves the calculation of that instant in future time when an object's position will be collinear with any zone boundary. Expressions of the future positions of all radii endpoints as well as that of each object in-play are manipulated using the vector definition of a linear combination. A system of simultaneous equations is developed and time of collinearity it is found.

to solve for time t of intersection of a point and a line:

$$(X_{i_t}, Y_{i_t}) = (X_{i_o}, Y_{i_o}) + (speed_c \times t \times \cos(\Phi_c), speed_c \times t \times \sin(\Phi_c))$$

i = 1, 2 for any two adjacent radii endpoints.

$$(X_{p_t}, Y_{p_t}) = (X_{p_o}, Y_{p_o}) + (speed_p \times t \times \cos(\Phi_p), speed_p \times t \times \sin(\Phi_p))$$

when points 1, 2 and p are collinear:

$$\alpha (X_{1_t}, Y_{1_t}) + (1-\alpha) (X_{2_t}, Y_{2_t}) = (X_{p_t}, Y_{p_t})$$

if $\alpha \in [0,1]$, the point p will lie between points 1 and 2 and a penetration takes place on this barrier.

The following 2 equation system is derived:

$$\alpha \times (X_{1_o} - X_{2_o}) + t \times (speed_c \times \cos(\Phi_c) - speed_p \times \cos(\Phi_p)) = X_{2_o} + X_{p_o}$$

$$\alpha \times (Y_{1_o} - Y_{2_o}) + t \times (speed_c \times \cos(\Phi_c) - speed_p \times \cos(\Phi_p)) = -Y_{2_o} + Y_{3_o}$$

rewrite as: $\alpha A + tB = C$, $\alpha D + tE = F$ solve $t = \frac{(-DC-AF)}{(AE-DB)}$

Equation Set 7. From-Without Next Penetration
(Continued on next page)

where:

1, 2 are subscripts denoting any two adjacent radii endpoints attributes.

Φ arctan (absolute value of the slope) for c and p.

c subscript denotes carrier attributes.

p subscript denotes penetrating object attributes.

o subscript denotes current time.

t subscript denotes future time.

t variable is future time of interest.

Equation Set 7. From-Without Next Penetration

The usual checks for division by zero are made. Since the algorithm does not distinguish between the time of entry or the time of exit, times are collected for further manipulation. The minimum positive time is used and a PENETRATION Event is scheduled (given the object's class and hull number and zone to be penetrated). This procedure calculates and schedules only the next most imminent PENETRATION Event for each object.

d. Penetration Survival

This routine effectively condenses the carrier battlegroup's many offensive and defensive capabilities into the simple mechanism of absorption by a zone. **Shapes of zones are the focus of this study. The objective is for the carrier to position its resources so as to maximize the time-in-zone for a given inbound threat.** Absorption of an object was considered to happen over time and NOT

instantaneously. Absorption is both a function of the carrier's current attention span consumption and its battle damage state.

User-defined probability density functions furnish the values used in the Monte Carlo technique employed here. The conditions of attention span and battle damage state were determined to be independent for this study. This allows the simple multiplication of the probabilities associated with attention span (BSY PTS) and battle damage (HT PTS). THe result is the test condition against which a random draw is compared in a standard fashion.

Inbound weapons are assigned BSY PT and HT PT values derived from their speed. That is, time-to-react till a platform enters Zone 1 is the criteria by which an inbound weapon is assigned a cost. A faster, more distant weapon may have a lower rating than a slower, nearer one. Available attention span is a function of the number and type of simultaneous tracking and countering operations conducted by the carrier. Attention span may be replenished as objects are removed from play either by absorption or by expiration of pre-set lifespans.

If the Monte Carlo mechanism indicated an absorption was to occur, an exponential distribution function was called given a mean lifetime per object per zone. A plausible estimate of an average travel distance per inbound object per zone, under favorable conditions for the carrier, was determined by the author. This distance was then divided by the object's maximum speed and an average lifetime yielded. At the end of this future time, the object was removed from the simulation scenario.

The success of an submarine's penetration may not only be seen as its passing through a zone unpenalized but also in its launching of a weapon before it is absorbed by a given zone.

e. Carrier Evasion PIM

This routine is called whenever the carrier obtains new information on the disposition of any opposing submarines. The carrier wants to avoid the danger of engaging the opposing submarines. The carrier's mission is to reach its destination intact and on time.

The purpose of this routine is to determine a path which represents the least exposure to known submarines' weapons. The first action taken is to superimpose a rectangular grid on the carrier's remaining area of possible movement. The repeat of Figure 9 is given below to visualize the process undertaken to establish this shortest path.

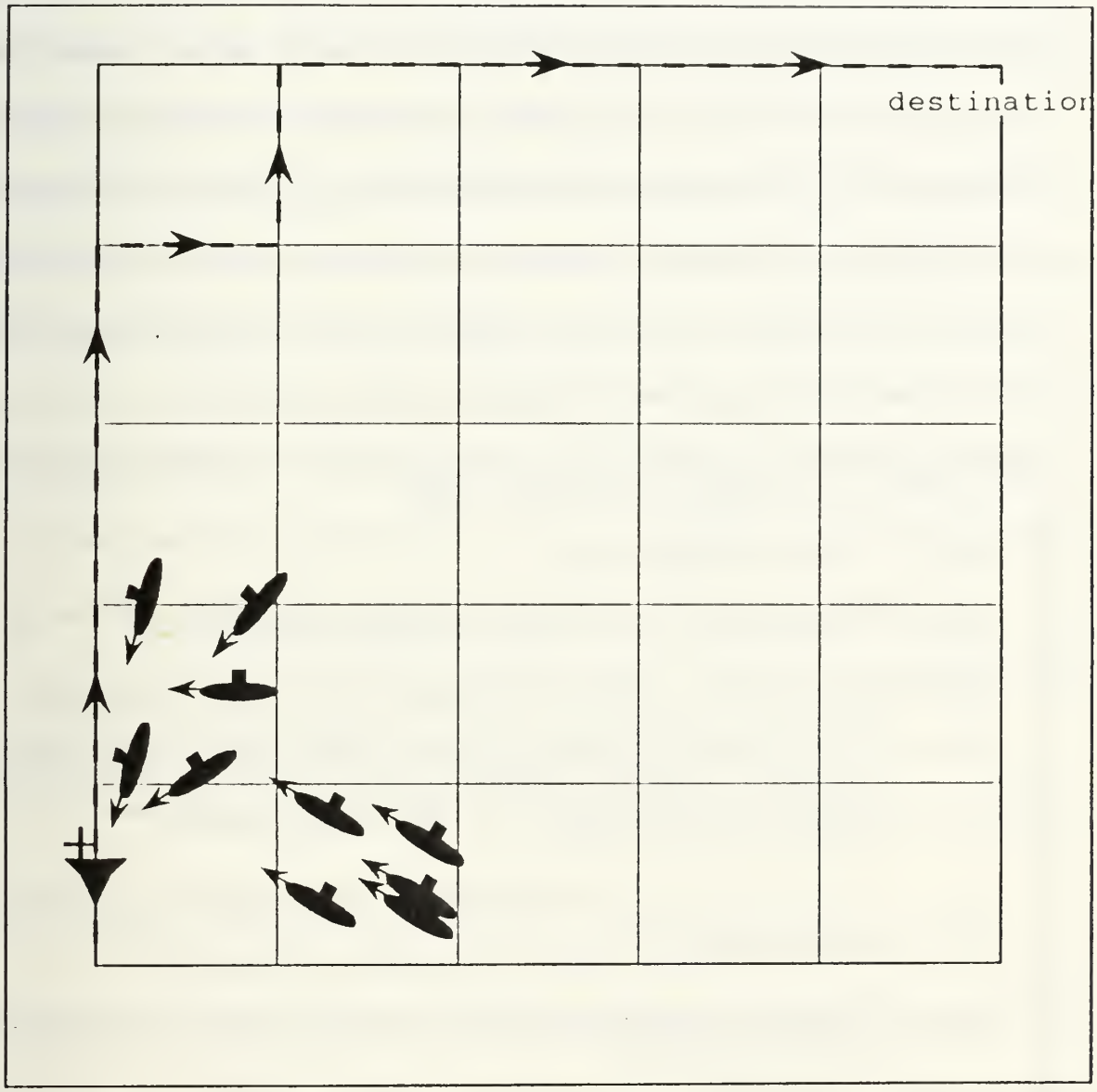


Figure 9. An Illustration of a Carrier Evasion PIM

Equation Set 8 below contains no math notation since most component algebraic operations have been discussed elsewhere. The carrier's current position defines the lower left corner and the carrier's destination forms the upper right corner of this grid. The X and Y distances are computed to establish equidistant horizontal and vertical segments, respectively, between each node on this imaginary grid. The nodes are named in a standard manner beginning with (0,0) in the lower left corner and ending with (m,m) in the upper right corner. Possible paths for a PIM are composed of either collinear or orthogonal adjacent segments.

to establish a carrier PIM with minimum danger

Step 1. Overlay rectangular grid

Step 2. Compute future carrier arrival times per each grid node.

Step 3. Determine all weapons within range of each node at appropriate times computed in step 2; Assign a lethality value for each weapon in range of all possible nodes per each value in set of carrier arrival times; Sum set of values for all weapons in range for each node as composite node weight.

Step 4. Sum all node weights for each of 252 possible paths; collect set with minimum value.

Step 5. If members of minimum value set exceed one, then randomly select a PIM from this set.

Equations Set 8. Carrier Evasion PIM Algorithm

The carrier's projected arrival times at each of these nodes is computed. These times are then used as an input for determining which of each type of submarine weapons could be within range beginning with the maximum range weapon currently in each submarine's inventory. These calculations use the carrier's scoreboard knowledge on each detected submarine's HULL NO, COURSE and SPEED. It was determined that the carrier would be given perfect knowledge of each opposing submarine's current onboard weapons load or inventory. This default condition was chosen since to try to describe the true nature of imperfect knowledge seemed too arbitrary. A value equal to the direct hit value of each type of weapon from every submarine within future range of each node was collected and summed for each node. This total weight was a danger or lethality value associated with each node. Each weapon was counted more than once. A weight was assigned to every node it could reach for each computed value of a future carrier arrival time.

Dijkstra's algorithm for the shortest path on a network was used as a means to solve for the required carrier PIM.

The carrier's orthogonal PIM segments are converted to near horizontal or vertical courses to maintain consistency with the Slope Function. The imposition of collinear or orthogonal course alternatives may, at first glance, appear to be too restrictive a constraint on the carrier's PIM. However, since new arrivals of information occur in any reasonable scenario, subsequent calls to this evasion routine will continue to cause a new carrier PIM to be computed. The carrier's actual historical track should not appear so artificial.

f. Submarine Attack-Weapon Launch

This routine is called whenever the submarine obtains new information on the disposition of the carrier. Each submarine wants to aggressively attack and destroy the carrier. As a member of a team, the submarine will engage in sacrificial actions for the accomplishment of the team mission despite the detriment to its own safety. Submarines have been made to relentlessly pursue the carrier even though they may not have any weapons in inventory or any hope of an attack solution given current steady-state conditions. The tactical advantage gained can either be a more accurate, third party fix or merely the consumption of the carrier's attention span which increases the likelihood of anothers submarine's successful attack.

The purpose of this routine is to determine, for each given submarine, a minimum point in future time at which that given submarine can acheive a firing solution for its current maximum range weapon; and then, to schedule a Launch Event.

The calculations are aimed at finding the first such LAUNCH Event for each submarine. First, all submarines with positive value speeds are examined from slow to maximum. If no LAUNCH Events are able to be scheduled this is referred to as a no attack criteria condition. If no attack criteria is met in the first step, negative speeds are next examined for each submarine to find a possible Launch Event time. The repeat of Figure 10 below illustrates typical relative player positions.

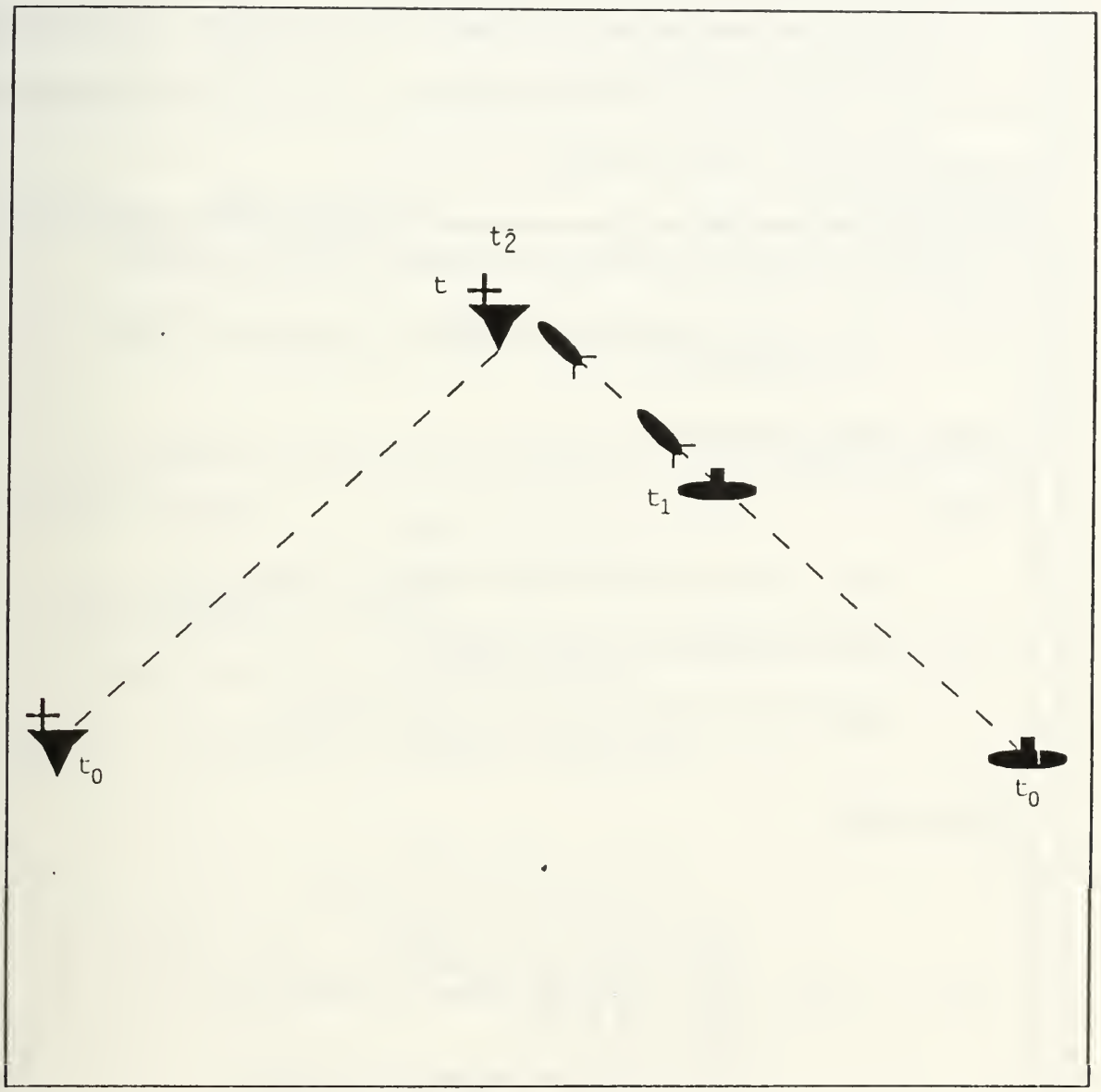


Figure 10. Submarine Attack-Weapon Launch

Quadratic expressions are used to solve for the required time of intersection of the carrier and the submarine's fired weapon. Equation Set 9 below shows the algebraic derivation and manipulation of the expression to find minimum future time in which the submarine may launch an attack. this is scheduled as a LAUNCH Event for each submarine.

to schedule a LAUNCH EVENT and a weapon REMOVE EVENT

NOTE 1: The reader should refer to Figure 11. Submarine Attack Consideration

BASIC FORMULATION $t = t_1 + t_2$

where:

t = carrier travel time from present position to point (X,Y)

t_1 = time till submarine launches weapon

t_2 = weapon travel time from time t_1 to point (X,Y)

DATA TABLE

$$\alpha = \arctan(\textit{carrier slope})$$
$$\gamma = \arctan(\textit{sub slope})$$
$$EE = X_c - X_s$$
$$FF = (\textit{carrier speed}) \times \cos(\alpha)$$
$$GG = \textit{sub speed}$$
$$HH = Y_c - Y_s$$
$$II = (\textit{carrier speed}) \times \sin(\alpha)$$
$$t_2 = \textit{weapon range}/\textit{weapon speed}$$

Equation Set 9. Weapon's Launch Algorithm
(continued on next page)

Step 1: to find t_1 using expressions for point (X,Y)

carrier	*cooordinate*	*submarine & weapon*
$X_c + (FF \times t) =$	X	$= X_s + (GG \times \cos(\gamma) \times t)$
$Y_c + (II \times t) =$	Y	$= Y_s + (GG \times \sin(\gamma) \times t)$

$$i.\ \cos\gamma = \frac{EE + (FF \times t)}{(GG \times t)} \qquad ii.\ \sin\gamma = \frac{HH + (II \times t)}{(GG \times t)}$$

$$NOTE\ 2: \quad (\cos\gamma)^2 + (\sin\gamma)^2 = 1$$

a. Use NOTE 2 to form generalized equation of second degree with t as variable of interest

$$At^2 + Bt + C = O$$

b. next substitute $(t_1 + t_2)$ for t

c. expand and re-express generalized form.

NOTE 3: t_2 is constant for each given weapon type

$$At_1^2 + Bt_1 + C = O$$

$$A = (FF)^2 + (II)^2 - (GG)^2$$
$$B = (2 \times A \times t_2) + (2 \times EE \times FF) + (2 \times HH \times II)$$
$$C = (2 \times EE \times FF \times t_2) + (2 \times HH \times II \times t_2) + (EE)^2 + (HH)^2$$

d. solve for t_1:

$$t_1 = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

Equation Set 9. Weapon's Launch Algorithm
(continued on next page)

Step 2.

given t_2 and having found t_1, compute t where $t_1 + t_2 = t$

t_1, is time of LAUNCH EVENT

t , is time of weapon hit target or (REMOVAL EVENT)

Step 3.

given t compute X,Y and then submarine course to X,Y using:

$$X = X_{sub} + (GG \times \cos(\gamma) \times t)$$
$$Y = Y_{sub} + (GG \times \sin(\gamma) \times t)$$

sub course = SLOPE (X_{sub}, Y_{sub}, X,Y)

Equation Set 9. Weapon's Launch Algorithm

Solving for required time, the denominator of the solution expression for the generalized equation of the second degree was tested for a non-zero value. A degenerate case could occur using this algorithm where the variable "A" in step 1 might equal zero. This condition was eliminated by construction. The discriminant was tested for a positive value and the resulting roots were examined.

Given two real roots, several types of situations could be pending. In the case where they both equal zero, it was determined that both objects must occupy the same position and have the same course and speed. This is not prohibited but is considered a degenerate case. Another degenerate case arises when both the roots are negative. This is explained as those points in past simulation time when launches could have occured along the players present courses. A combination of a positive

root and a negative root determine that a launch could have already occured and that a second opportunity is about to occur. Two positive roots imply that both events have yet to occur. The minimum of these is chosen to schedule the next Launch Event.

The other root is ignored. By construction, all weapons are designated to be launched as soon as a first launch per type is initiated. (That is, with individual rates of simultaneous fire assigned per type and specific intervals between volleys set for reloading weapons per type and submarine type.)

If no attack criteria can be found for a given submarine, then a course and speed are assigned in the following arbitrary manner:

1. The distance between the submarine and the carrier is computed.
2. This distance is divided by the submarine's maximum speed to yield a time increment.;
3. The point where the carrier would be at this time in the future is then calculated.
4. This point is then assigned as the submarines destination and its course computed.

The justification for this tactic is given by the fact that the weapons carried by the submarine generally possess speeds far in excess of either the carrier or the submarine. This fact, combined with the provision that a weapon is usually fired at less than its maximum range, yields the option of a flank approach with a wide window of launch-time should the carrier slow for replenishment or favorably change course. These calculations are straightforward and are not shown here.

g. Replication End & Summary Statistics

The discussion in this section covers those activities which entail listing of summary values for any measures of effectiveness, releasing memory and emptying the event calendar for the next replication, and, finally, the listing of values for all player attributes. A full listing of all player attributes is given in Appendix A. Appendix B provides input files which show which of these attributes are user-defined.

A replication may end under several diverse conditions which are listed below in their entirety:

1. Penetration of Zone 1 by a submarine.
2. Zeroing out of carrier's battle damage points.
3. Enroute at expiration of time alloted; SOA is not met.
4. Arrival of carrier to destination; SOA is met.

The reader should note that conditions one through three above contribute to the sum of the number of trials which are considered FAILURES. Only condition four contributes to the sum which represents SUCCESS.

Gameover is the first routine called whenever a stopping condition occurs. It, in turn, calls Stats and Report. Gameover releases memory consumed by the objects and their attributes. These are reinitailized at the beginning of each replication. An algorithm is also executed which empties the event calendar of all scheduled events in anticipation of beginning the next replication.

Stats invokes a SIMSCRIPT II.5 system function which automatically lists every attribute of each object in the simulation as of the current time. For those entities previously removed, their attribute values as of the time of their removal have remained stored. All values are output here to an external ASCII file. Examples of this type of output are provided in Appendix C.

Report was specifically set aside to collect information on each experiment's measures of effectiveness. A simple sum of the number of CV_WINS and the number of CV_LOSES was chosen initially. Since this study never reached maturity, these remain in this simplistic form.

C. CONCEPTUAL EXPERIMENTAL DESIGN

The ideas presented in this section are preliminary in nature but are included in the discussion for the sake of completeness. SINCE THE FULL IMPLEMENTATION OF THE MODEL WAS NEVER ACHIEVED, this portion of the study was never refined. Here, an experiment is taken to mean the full set of differing trials. A trial is composed of a number of replications where the input values are all the same but different values drawn from probability distributions may cause different results for a given replication.

1. Proposed Measures of Effectiveness

The design of this model was intended to provide a rich set of variables for the analyst to manipulate. A model which specifically allows for manipulation of many factors provides a framework for sensitivity analyses which might discover unexpected relationships in the behavior of the system.

An extremely simple measure of effectiveness(MOE) was adopted for purposes of beginning this study. A point estimate of the probability of successful transit was chosen, along with its complement, the probability of failure of the carrier to reach its destination.

2. Proposed Experimental Design

The shape of the carrier's zones, as a proxy for the disposition of certain types of battlegroup asset capabilties, is the primary concern for this investigation. The null hypothesis for this experiment is that there is no significant difference in the ASW screening doctrine chosen by the carrier on the outcome of the carrier's likelihood of a successful open ocean transit. Hence, we would like to, at the end of this proposed experiement, be able to claim that there exists a statistically significant advantage, in terms of success rate, in reshaping screen doctrine. The available statistical tools allow the investigator to analyze the results in terms of their significance.

Given the above MOEs, a full factorial design was conceived. Factorial design focuses on critical factors which are manifested by assuming only one of two values; arbitrarily called high or low. Table 11 below shows a proposed design.

Table 11. A Proposed Full Two Factor Design

ONE	a. - 120 degrees sector search
ONE	b. - 360 degrees area search
TWO	a. - Torpedoes only
TWO	b. - Missiles and Torpedoes
THREE	a. - Dumb like dart
THREE	b. - Persistent like predator
FOUR	a. - Each only knows what it discovers
FOUR	b. - Carrier has prior knowledge of enemy

This study was intended to investigate the above factors:

ONE	ASW Zone Shape;
TWO	Weapon Mode;
THREE	Weapon Type; and,
FOUR	State of Prior Information.

Factor 1 is the HYPOTHESIZED variable of interest in this study. ONE a) represents the current U. S. Navy ASW screening doctrine of the bent-screen, narrow, forward-looking tactic. ONE b) represents a generalized look-in-all-directions tactic.

Factor 2 was meant to reveal the significance that the combination of missiles and torpedoes has, versus that of the torpedo alone, on the carrier's probability of successful transit. TWO a) was set to a torpedo-only threat and used to simulate the threat assumed in the limiting lines of approach doctrine (ONE a)).

TWO b) was set to both missiles and torpedoes which simulates the author's opinion of the real threat which demands the new coverage tactic (ONE b)).

Factor 3 was included to test for the significance of sophisticated weaponry against weapons that were merely non-reactive projectiles.

Factor 4 is meant to key on the pivotal role of scouting information on the outcome of a struggle to gain the decisive tactical advantage. In other words, if the quality of information derived from strategic assets is such that it allows the carrier a sufficient margin against the enemy, without a change in ASW screening doctrine, then a National Defense policy might be suggested that focuses investment in enhancing strategic surveillance capabilities instead of, or along with, pursuing a better ASW screening doctrine.

This design is intended to show that there is indeed a problem with the current ASW screening technique in that looking ahead too narrowly makes the carrier vulnerable to a flank surprise attack. The significance of Factor 1 would have been tested using standard Analysis Of Variance Techniques (ANOVA).

3. Proposed Statistical Considerations

A point estimate of the probability of successful transit was to be estimated for each of the two sets of eight trials for this experiment. Analysis of variance was to be used to test if screen shape does significantly affect the probability of successful transit. If the shape factor should have proved to be significant, as a result of a comparison of the results of these trials, then a fresh examination of U.S. Navy ASW screening doctrine would seem appropriate.

a. Analysis of Variance

The Analysis of Variance is used to see if the difference in the results of experimental trials might be due to chance or experimental error. If these differences cannot be explained in this manner, then a significance in the results can be attributed to the values for the different applicable factors in the trials composing an experiment. The number of replications per trial would have been set here to 100 and this figure is assumed in the remaining discussion.

There are three major assumptions in the analysis of variance:

1. Normality;
2. Homogeneity of Variance; and,
3. Independence of Errors.

Assumption number one would be met here since the total number of trials per shape factor is large (100 replications x 8 trials = 800). Assumption number two states that the variance within each trial or set of replications should be distributed equally across all trials. This assumption is needed to combine, or pool, all within-trial variances into a single within-experiment calculation. If unequal sample sizes are allowed to exist then this would likely lead to unequal variances. This points out the efficacy of the controlled nature of a simulation experiment which affords one the ability to set the number of replications equal for all trials in an experiment. The third assumption speaks to the difference of each point estimate(sample estimate of the probability of successful transit) from its true value (population

mean). The error for one observation should not be related to the error for any other observation.

Prior to constructing an analysis of variance table, it is usually considered prudent to test the distribution of the errors, or residuals, for normality. In addition, one should perhaps plot [Ref. 14:p. 1] the relationship between the residuals and the expected value of the response to see if there is any apparent correlation.

b. Common Random Numbers

Common Random Numbers can be used in the conduct of all trials in order to reduce the variance associated with the point estimates yielded from the analysis of the factor of interest; ASW Zone Shape. This means that the set of observations (within-trial critical values) across each trial are constructed to be correlated. The raw results of point estimates for the probability of success from each set of trials, when compared by taking the difference of the two quantities, yields a new quantity little value; its corresponding variance cannot be estimated.

As shown in Equation Set 10, a slight manipulation of the above difference-in-sums quantity yields the sum-of-the-differences of each replication's estimate for a given set of two trials. This sum is then divided like the first quantity by the number of replications. The resulting statistic takes advantage of the fact that the original point estimates were derived from the same set of random numbers. In the formula for the variance for this statistic, a covariance term ends up being subtracted from the sum of the variances of the original point estimates: this may in fact reduce the variance of the statistic. This approach is addressed in the following:

> ...It is a general belief and empirical observation, though not a proven fact(Schruben and Margolin, 1978), that using identical input streams will create positive correlation in the outputs... [Ref. 11:p. 216]

c. A Suggested Composite Estimate

The above statistical treatment of hypothetical results suggests the need for a new composite statistic. This statistic would provide a test for any possible incremental improvement provided by the high value for the ASW zone over the low. Such a new composite estimate could be formulated as shown below in Equation Set 11: as a quadruple sum of the difference between every replication point estimate of these two shape treatments, varied over the other three factors and divided by the total number of replications (i.e. 800 as shown above).

raw results of two trial's point estimate comparison

$$\hat{P}1 = \frac{\Sigma x_i^1}{n}$$

$$\hat{P}2 = \frac{\Sigma x_i^2}{n}$$

where:

$\hat{P}1$ = point estimate of probability of sucess of trial 1.

$\hat{P}2$ = point estimate of probability of sucess of trial 2.

x_i^1 = for i = 1 to n, the trial estimate of the probability of success for trial 1

x_i^2 = for i = 1 to n, the trial estimate of the probability of sucess for trial 2

n = number of replications

"raw" statistic = $(\hat{P}1 - \hat{P}2)$ with unknown variance

Equation Set 10. Common Random Numbers
(Continued on next page)

$$\text{new statistic} = \hat{d}$$

$$\text{let } D_i = \sum_{i=1}^{n} (X_i^1 - X_i^2)$$

$$\text{let } \hat{d} = \frac{Di}{n}$$

$$\text{variance of } D = var(X_i^1) + var(X_i^2) - 2cov(X_i^1, X_i^2)$$

given common random numbers $2cov(X_i^1, X_i^2)$ is likely > 0 thereby reducing VAR(D).

Equation Set 10. Common Random Numbers

to formulate a statistics to test for the incremental improvements in a new proposed ASW screen shape on the probability of success over the current method

$$let\ \hat{p} = \frac{\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} X_i^{jkl} - Y_i^{jkl}\right)}{n}$$

X_i = ASW zone shape as low

Y_i = ASQ zone shape as high

j,k,l = high or low

where:

n = number of replicatiions; here (2^3 x 100) = 800
i = ASW zone shape
j = weapon mode
k = weapon type
l = state of prior information
$\hat{p}$ = probability of sucessful transit (point estimate)

$VAR(\hat{p}) = n\hat{p}(1-\hat{p})$ variance is known (binomial form)

significance test:

does $\hat{p} \pm (\sqrt{VAR(\hat{p})}) \times Z_{1-\frac{\alpha}{2}}$ *include* 0

Equation Set 11. A Suggested Composite Statistic

The final step would be to test the variance of this incremental improvement of the high value shape factor to see if the range (a distance of the square root of the variance above and below the point estimate) contains zero. If it does not, then one could be reasonably confident that there was indeed a significant

incremental improvement made in adopting an all around ASW screening doctrine similar to the one hypothesized.

D. SIMSCRIPT II.5 MODELLING DIFFICULTIES

The discussion of the author's difficulties with the SIMSCRIPT II.5 simulation programming environment should not be construed in a negative light. The topics discussed below might be encountered by any analyst using a well known and recognized simulation product. It seems expectable that each new study should stress a standard programming package in some new way.

The author's over-reliance on the existing SIMSCRIPT II.5 documentation published by CACI,INC. [Ref.'s 15, 16, 17, & 18] and the lack of interaction with CACI,INC. consulting services was fatal. Therefore, it can be supposed that some of the difficulties raised in this section could have been avoided by reliance on the expert help available from the vendor.

A general comment about SIMSCRIPT II.5 is that its design philosophy is becoming outdated. Its origins go back to times when computer memory needed to be conserved. Many of the features of this programming environment are a direct result of the language's design goal to minimize the consumption of computer memory. This concern is relevant but should no longer be dominant. The resulting constraints are too confining for all but academic exercises.

1. Permanent Entity Structure

This first topic deals with a significant setback to the author. The problem, and my solution to it, illustrate the advantage an expert's contribution could have

made. SIMSCRIPT II.5 handles objects as one of three types of entities; permanent, temporary, or compound. Each entity may have have associated attributes and belong to various sets. A permanent entity's attributes may be addressed using subscripts which identify the particular player. Temporary entities require some peculiar constructions in order to be manipulated using subscripts.

Compound entities are a combination of permanent and temporary entities. Very little information is provided concerning compound entities. It may well have been that this type of object would have met the requirements of this model's specification. No further reference will be made to such a compound entity.

Permanent entities are such because they are assigned memory for the duration of a simulation replication. A temporary entity's memory is allocated and deallocated during a given replication. A temporary entity construct was chosen for the weapons. In this instance, since the number of weapons was expected to be large, it was not deemed prudent to permanently consume memory. Weapon objects were designed to exist only once fired and to expire upon reaching their target. All other objects were assigned as permanent entities.

The original design planned on using a multi-dimensional subscript entity addressing technique. This was desired in order to avoid setting arbitrary limits on the numbers of players. It was hoped that constraints on the complexity of the scenario would be a function of the computing machinery and not that of the analyst's or programming environment's construction.

It was with dismay that the author discovered that a permanent entity is really only a one-dimensional array. What was desired was a flexible, ragged array. It seemed reasonable to expect that an entity attribute should have the capacity to take on more than one value over the course of a replication; that there should be some ready provision for a range of values.

It became necessary to select a finite number of players per class of object and to construct specific arrays with specific names in order to proceed with the project. This caused an EXCESSIVE redundancy in the program coding. Similar routines had to be repeated where tightly nested loops would have been sufficient if multi-dimensional subscripting had been supported. This was an order of magnitude impact on the number of lines of code produced(20,000). Editting and compiling activities became endurance sessions and introduced many opportunities for hard-to-discover typograhical errors. The result is woefully inelegant code that has not been fully debugged.

2. System Variable Accessability

As was mentioned earlier, it was required to construct routines to unschedule particular classes of events (remove them from the event calendar) in order to proceed to calculate a new most imminent event based on the new state. SIMSCRIPT II.5 assigns a simulation time value called TIME.A to the temporary entity which is an event notice, or place holder, in the event calendar. All reference to this variable is as if it is available to the user for his own manipulation. Initial design considerations were based on this assumption. It was believed that specific

events could be maniuplated or unscheduled easily. This was NOT found to be the case. A redesign of basic program flow was necessary in order to implement a compromise method of unscheduling specific classes of events. This too contributed to explosive code growth.

3. Input/Output File Limitations

Due to the design goal of having a rich set of variables with which to experiment, the debugging process was hampered by the author's inability to open more than one output file at a time. This resulted in a file size that went beyond the 32,000 line limit of most MS-DOS editors. This necessitated limiting the information to be recorded for a given set of replications. Explicit commenting of many print statements was required, and, along with each set of changes, a new compilation was required.

4. Compiler Idiosyncracies

The working source code file size was approximately 20,000 lines. EACH compilation on average took 30 minutes on a 386, 25 megahertz, 14 megabytes of RAM, computer.

The SIMSCRIPT II.5 application environment is known as SIMLAB. SIMLAB's partial compile capabilty was not seen to operate consistently. Only those source code modules which have changed from the last compilation are advertised as needing compilation for a next iteration. This was intended as a time saving feature. Too often error messages were returned that bore no relation to fact. Use of this facility was discontinued.

SIMLAB also contains a built-in text editor. It seems that the compilation mechanism required a SIMLAB editor file designator before it would operate. This led to a required conversion sequence which was an annoyance.

5. Run-Time Debug Facility Output

This facility was well designed but lacking somewhat in its execution. Output was confined to go only to the virtual terminal screen and the display of all variable values was in hexadecimal notation. Both of these features should be improved as they needlessly impede the analyst.

6. System Run-Time Errors

The abrupt abort of the SIMLAB debug facilty AND ITS SUBSEQUENT EXIT of the SIMLAB environment was another setback. All conditions not anticipated by the product developers were handled in this manner. An expectable run time error, like an attempt to address a subscripted entity beyond its defined array boundary, aborted the program. No trace back information was provided. Due to the amount of redundant code, this was not an uncommon occurance.

The last phenomenon encountered before the coding effort was halted was the MOST BAFFLING. The SIMLAB compilation routine itself produced this very abrupt abort condition. No time was left to ascertain what could have caused this behavior. It would seem reasonable to expect the SIMLAB compiler to produce some information on all fatal conditions. The offending source code subroutine was identified but the cause of the error was never isolated. This subroutine calculated

which missile was to penetrate next. A similar subroutine for torpedoes compiled with no errors.

The author is left puzzled as to how a system level routine, such as a compiler, can suffer a catastrophic failure mode.

E. MODEL AVAILABILITY

THE FULL IMPLEMENTATION OF THE SIMULATION PROGRAM HAS NOT BEEN, NOR IS IT INTENDED TO BE, ACCOMPLISHED BY THE AUTHOR. The reader is cautioned that the computer program developed in this research has not been completed. Anyone requesting copies of code written to date must assume that both logic and computational errors still exist. The source code, such as it is, may be obtained from the author at the following address:

Commanding Officer
Code FW43
Flight Test and Evaluation Group
Naval Air Warfare Center Aircraft Division
Patuxent River, MD 20670-5304

VI. METHODOLOGY CRITIQUE

As with any simulation model no matter how clever or elegant abstractions and algorithms, the utility of the results are in large part determined by the quality of data required to run the model. This is often a primary weakness of most simulation model analyses.

Some of the data required to use the model developed for this thesis does not exist. The cumulative distribution functions for attention span and battle damage were simply hypothesized. The method of determining the mean lifetimes of detected penetrating objects was also just a construction. Other more familiar data associated with probability of detection, acoustic or electromagnetic, or reliability errors, is only partially available on some specific weapons systems performance in specific environments. Therefore, the reader is cautioned that over on above any limitations in the abstractions employed, the model specified relies on data which simply does not exist.

A. UNIQUE CONCEPTS

All simulation model analyses should be accompanied by a discourse on the prospective impact that key abstractions may have on the study's results. The discussion presented here will attempt to address those implementation decisions which are believed to have significance.

1. Carrier Zones

The notion that the offensive and defensive capabilities of a carrier battlegroup could be adequately portrayed by a polygonal area with certain properties is the key abstraction of this model. Any fundamental weakness or mistake in this step could conceivably make the conclusions of the entire study questionable.

These areas are referred to as Zones one through five, from inside to outside. Each has its own unique features. Recall that Zone 1 is the carrier iself; Zone 2 represents that area covered by the carrier's AAW; Zone 3 is that area covered by surface-to-air missiles; Zone 4 is that area that represents the ASW screen; and, Zone 5 is that area which is controlled by the carrier's aircraft.

a. Homogeneity

Each set of radii defines a unique isotropic zone of weapon system capability. The real world is full of holes in coverage or differing densities of coverage. Thus, it seems that a conservative approach is warranted towards any results indicated by the model. It has been assumed that the long run average density exists for each point in the covered region. Therefore, the isotropic property can be seen to be like an evenly distributed expected value of the density of coverage.

b. Contiguity

All zones originate at the carrier's position so they overlap. Because the carrier is maneuvring, it is possible that a penetrator may enter and leave a zone several times. The object will still expire at its first designated time as a result of an

initial penetration. In all other respects, zones are considered not to overlap. If an object is vulnerable in two adjacent zones, then a new computation for successful transit is required.

c. Absorption Property

This concept is a unique feature of the model. It implicitly suggests the notion that the carrier must accept and prepare for battle damage. Intimidation of an adversary is not considered an option. The seriousness of the opposition's intent to destroy the carrier requires that the carrier expend maximum energy towards minimizing the opposition's unpenalized time to launch weapons. Therefore, this absorption formula views the carrier zones as AMOEBA- LIKE MASSES consuming everything in their path.

Thus, a penetrator can never escape the carrier's influence, allowing the merger of many separate battlegroup functions into a tractable few. It could be viewed as a postulation for set of desired qualities more than an abstraction of real-world properties. Such would be the ideal functioning of a zone; to never let a detected adversary escape. This implies a certain cost to eliminate the object and requires sufficient firepower to dominate the engagement. The worst strategy possible for a naval vessel is to engage a superior force in an exchange of firepower. Therefore, this absorption notion implies a certain quality of readiness and attention capacity for the carrier.

The mechanism invoked to achieve the absorption is a series of Monte Carlo routines where successful passage through the carrier's outer zones always ends

at its innermost zone. This last arrival results in either the object's or the carrier's demise. Unlike most Monte Carlo techniques, the decision is not a simple pass or fail upon entry to new zone. The assignment of a finite lifespan upon meeting the fail criteria lends a realism to this aspect of the absorption property. Upon detection, submarines are unlikely to immediately lose their capabilty to consume attention span or launch weapons.

A weakness in the current specification is that the zones maintain a constant capacity over time. Only attention span or battle damage can change this capacity which implies that crews and equipment could sustain peak performance indefinitely if these factors were to remain unchanged.

2. Carrier Sensors

Two factors deserve mention here. The fact that the carrier was made to rely solely on remote sensing assets and, that accuracy of these sensors was treated as a function of time.

Remoteness of the carrier's detecting assets was at first conceived as an accomodation to the absorption property. The perspective that most ASW searches are somehow cued from beyond a given carrier's assets seems to justify the initial decision. The author cannot imagine any positve or negative effects this implementation might have on experimental results.

Accuracy, as a function of time, was viewed as an expedient proxy for the combination of factors which affect a sensor systems performance. This was a defensive decision and meant to avoid gross mistakes in characterizing the complex

behavior of electromagnetic and acoustic sensor systems and the environment. It was hypothesised that all of the variables which factored into this behavior could be reduced to a uniform probability distribution. Rather than have preconceived notions about the validity of this decision, the author had intended to investigate the sensitivity of the model's results to slight changes in the critical parameters of this random distribution function.

3. Carrier Evasive PIM

The nature of an engagement model is to test tactics. Tactics are concerned with action and counter-action of opposing players. A principal component of any tactic is the maneuvering to gain tactical advantage. The goal is to give the carrier some sort of intelligent means of avoiding the threat. The idea of assigning each carrier way point a weight is appealing. A network optimization problem began to form. The objective became to find the shortest (least lethal) path.

a. Orthogonal Courses

The carrier's projected arrival times at each grid node is computed. These times are then used as an input for determining which of each type of submarine weapons could be within range of of each given node. These calculations use the carrier's scoreboard knowledge on each detected submarine's HULLNO, COURSE and SPEED.

It was determined that the carrier would be given perfect knowledge of each opposing submarine's current onboard weapons load or inventory. This default condition was chosen since to try to describe the true nature of imperfect knowledge

seemed too arbitrary. A value equal to the direct hit value of each type of weapon from every submarine within future range of each node was collected and summed for each node. This total weight was a danger or lethality value associated with each node. A weapon was counted more than just once. It added a weight to each node it could reach for each computed value of a future carrier arrival time which were sets of grid nodes. This seemed like a fair method for accounting for the potentiality implied in the calculation.

The carrier's orthogonal PIM segments are converted to near horizontal or vertical courses to maintain consistency with the Slope Function. The imposition of collinear or orthogonal course alternatives may, at first glance, appear to be too restrictive a constraint on the carrier's PIM. However, since new information is arriving in a reasonable scenario, subsequent calls to this routine will continue to cause a new carrier PIM to be computed. The carrier's actual historical track does not appear to have been influenced adversely by this decision.

A description of the effect of this algorithm would have been an ancillary outcome of the full implementation of this study.

4. Role of Information

Information is what causes significant changes of states in the real system under study. Therefore, it is the mechanism by which the simulation scenario was driven. All manipulation of the event calendar was prompted by changes in information states. Information is finally made available to the objects themselves as well as to their team members. The TIME of the sighting, the identity of the

SEEN, its POSITION, COURSE, and SPEED are all there for inspection. These are posted on that team's scoreboard, the most recent information is posted. The ultimate effect this may have on simulation outcome is difficult to predict. This represents yet another candidate parameter to have varied and measured.

The construction of a team network (Scoreboard) for sharing information directly mimics the real system under investigation. The instant access to information, once it is on the net, is an artifice that was done for implementation ease. It is not considered to contribute or detract from the possible outcome of any trial. The time lag associated with all reported information can be viewed as also accounting for variance in the real scenario's information systems.

B. OTHER CONCEPTS

Other model concepts that are worth note but not exposition are simply listed below as a reminder to the reader of the extent and type of limitations in any specification's design:

1. Cartesian Plane/Linearity/Instantaneous Changes
2. No Interaction With Environment
3. No Interaction With Humans
4. Independence of Attention Span and Battle Damage
5. Attention Span's Restoration Capabilty
6. Battle Damage's Lack of Restoration Capability
7. One Carrier Constraint
8. Zones as 12 Sided Polygons

9. Player Types, Numbers, Attributes
10. Aircraft and Satellite Fixed PIMs
11. Submarine as Only Shooter
12. Submarine's PIM Given No Attack Criteria

VII. RESULTS/CONCLUSIONS

The model specified was hard to implement because of its sophistication. I failed to finish the task.

It is clear that only the first stated goal has been achieved namely, to specify the simulation model. The maturity of the code is in that uncertain region described as ALMOST running. No results have been obtained.

Lastly, the analyst attempting any complex or sophisticated study should be teamed in some cooperative manner with the developer of the simulation programming environment. Inevitably, both useable system features and undesireable behavior will be known but UNDOCUMENTED; even by the best of product developers. Avoidable inefficiencies will be built into the process if this type of relationship cannot be formed.

The full set of trials posed for the experiment discussed in this paper are destined to remain a conceptual exercise for this author. A conclusion HAS NOT proceeded from my premise. However, my belief is that the U.S. Navy should revisit its ASW Screening policy. This study has produced no supportable indications on this issue other than to raise it.

In the 1990's there will be threats to U.S. maritime independence that current U.S. Navy tactical ASW screening doctrine is unable to address.

APPENDIX A. SIMSCRIPT II.5 DECLARATIVE ROUTINE LISTING

The listing below is the actual source code for the PREAMBLE routine in SIMSCRIPT II.5 source code. It is intended to provide the reader with a complete sense of the proposed model's structure and to substantiate the claims made for the model's richness.

```
preamble

events include CV_SOA and CV_UNREP

every CV_WAY_PT
      has a CV_WPT_FROM_TIME
      and a CV_WPT_FROM_PLACE

every LS_WAY_PT
      has a LS_WPT_HULLNO

every RC_WAY_PT
      has a RC_WPT_HULLNO

every CV_DETECTION
      has a CV_DET_MODE
      and a CV_DET_SEER_CLASS
      and a CV_DET_SEER_HULLNO

every LS_DETECTION
      has a LS_DET_MODE
      and a LS_DET_SEER_HULLNO
      and a LS_DET_SEEN_HULLNO

every CV_INFO_TO_LS
      has a CV_BRD_TIME_SEEN
      and a CV_BRD_X
      and a CV_BRD_Y
      and a CV_BRD_COURSE
      and a CV_BRD_SPEED
```

every LS_INFO_TO_CV
    has a LS_BRD_TIME_SEEN
    and a LS_BRD_HULLNO
    and a LS_BRD_X
    and a LS_BRD_Y
    and a LS_BRD_COURSE
    and a LS_BRD_SPEED

every CV_LOSE_CONTACT
    has a CV_LCT_MODE
    and a CV_LCT_SEER_CLASS
    and a CV_LCT_SEER_HULLNO

every LS_LOSE_CONTACT
    has a LS_LCT_MODE
    and a LS_LCT_SEER_HULLNO
    and a LS_LCT_SEEN_HULLNO

every LS_PENETRATION
    has a LS_PEN_HULLNO
    and a LS_PEN_ZONE

every RC_PENETRATION
    has a RC_PEN_HULLNO
    and a RC_PEN_ZONE

every IW_PENETRATION
    has a IW_PEN_CLASS
    and a IW_PEN_HULLNO
    and a IW_PEN_ZONE

every LS_LAUNCH_IW
    has a LS_LIW_WEAPON
    and a LS_LIW_HULLNO

every RC_START
    has a RC_RCS_HULLNO

every LS_REMOVE
    has a LS_REM_HULLNO
    and a LS_REM_FROM_TIME

```
        every RC_REMOVE
                has a RC_REM_HULLNO
                and a RC_REM_FROM_TIME
                and a RC_REM_FROM_PLACE
                and a RC_REM_FROM_ZONE

        every IW_REMOVE
                has a IW_REM_CLASS
                and a IW_REM_HULLNO
                and a IW_REM_FROM_TIME
                and a IW_REM_FROM_PLACE
                and a IW_REM_FROM_ZONE

define  CV_WPT_FROM_PLACE,
                LS_WPT_HULLNO,
                RC_WPT_HULLNO,
                CV_DET_MODE,
                CV_DET_SEER_CLASS,
                CV_DET_SEER_HULLNO,
                LS_DET_MODE,
                LS_DET_SEER_HULLNO,
                LS_DET_SEEN_HULLNO,
                CV_BRD_SPEED,
                LS_BRD_HULLNO,
                LS_BRD_SPEED,
                CV_LCT_MODE,
                CV_LCT_SEER_CLASS,
                CV_LCT_SEER_HULLNO,
                LS_LCT_MODE,
                LS_LCT_SEER_HULLNO,
                LS_LCT_SEEN_HULLNO,
                LS_PEN_HULLNO,
                LS_PEN_ZONE,
                RC_PEN_HULLNO,
                RC_PEN_ZONE,
                IW_PEN_CLASS,
                IW_PEN_HULLNO,
                IW_PEN_ZONE,
                LS_LIW_WEAPON,
                LS_LIW_HULLNO,
                RC_RCS_HULLNO,
                LS_REM_HULLNO,
                RC_REM_HULLNO,
                RC_REM_FROM_PLACE,
```

```
            RC_REM_FROM_ZONE,
            IW_REM_CLASS,
            IW_REM_HULLNO,
            IW_REM_FROM_PLACE and
            IW_REM_FROM_ZONE
            as integer variables

define  CV_WPT_FROM_TIME,
            CV_BRD_TIME_SEEN,
            CV_BRD_X,
            CV_BRD_Y,
            CV_BRD_COURSE,
            LS_BRD_TIME_SEEN,
            LS_BRD_X,
            LS_BRD_Y,
            LS_BRD_COURSE,
            LS_REM_FROM_TIME,
            RC_REM_FROM_TIME and
            IW_REM_FROM_TIME
            as double variables

        permanent entities

        every CV
            has a CV.IN.PLAY
            and a CV.CLASS
            and a CV.HULL.NO
            and a CV.DEST.X
            and a CV.DEST.Y
            and a CV.SOA
            and a CV.UNREP.TAG
            and a CV.UNREP.INTERVAL
            and a CV.UNREP.PERIOD
            and a CV.LAST.SPEED
            and a CV.MAX.SPEED
            and a CV.CRUISE.SPEED
            and a CV.SLOW.SPEED
            and a CV.MAX.SEEN.AC
            and a CV.CRUISE.SEEN.AC
            and a CV.SLOW.SEEN.AC
            and a CV.EM.PROB
            and a CV.BUSY
            and a CV.POINTS
            and a CV.X
```

and a CV.Y
and a CV.SEES.LS
and a CV.PATH.RECORD
and a CV.PATH.LEG
and a CV.SLOPE
and a CV.SPEED
and a CV.STOP.TIME
and a CV.SCBD.TIME
and a CV.SCBD.X
and a CV.SCBD.Y
and a CV.SCBD.SLOPE
and a CV.SCBD.SPEED
and a CV.NEXT.WAY.PT
and a CV.NEXT.UNREP

define CV.DEST.X, CV.DEST.Y, CV.SOA,CV.UNREP.INTERVAL, CV.UNREP.PERIOD, CV.MAX.SEEN.AC, CV.CRUISE.SEEN.AC, CV.SLOW.SEEN.AC, CV.EM.PROB, CV.X, CV.Y, CV.SLOPE, CV.STOP.TIME, CV.SCBD.TIME, CV.SCBD.X, CV.SCBD.Y, CV.SCBD.SLOPE, CV.NEXT.WAY.PT and CV.NEXT.UNREP
as double variables

define CV.IN.PLAY, CV.CLASS, CV.HULL.NO, CV.UNREP.TAG, CV.LAST.SPEED, CV.MAX.SPEED, CV.CRUISE.SPEED, CV.SLOW.SPEED, CV.SPEED, CV.BUSY, CV.POINTS, CV.SEES.LS, CV.PATH.RECORD, CV.PATH.LEG and CV.SCBD.SPEED as integer variables

every LS
has a LS.IN.PLAY
and a LS.CLASS
and a LS.HULL.NO
and a LS.MAX.SPEED
and a LS.CRUISE.SPEED
and a LS.SLOW.SPEED
and a LS.EM.PROB
and a LS.AC.PROB
and a LS.MAX.SEEN.AC
and a LS.CRUISE.SEEN.AC
and a LS.SLOW.SEEN.AC
and a LS.MAX.SEER.AC
and a LS.CRUISE.SEER.AC
and a LS.SLOW.SEER.AC
and a LS.AC.DETECT.RANGE

and a LS.AC.UPDATE.INTERVAL
and a LS.LOW.LATE
and a LS.HIGH.LATE
and a LS.PATH.RECORD
and a LS.PATH.LEG
and a LS.X
and a LS.Y
and a LS.SLOPE
and a LS.SPEED
and a LS.MAX.WEAPON
and a LS.BUSY
and a LS.SEES.CV.AC
and a LS.CV.DIST
and a LS.SCBD.TIME
and a LS.SCBD.X
and a LS.SCBD.Y
and a LS.SCBD.SLOPE
and a LS.SCBD.SPEED
and a LS.NEXT.WAY.PT
and a LS.NEXT.DETECTION
and a LS.NEXT.LOSE.CONTACT
and a LS.NEXT.PENETRATION
and a LS.NEXT.LAUNCH.IW
and a LS.LAST.PEN.ZONE
and a LS.REMOVE
and may belong to a 2LSAC

define LS.EM.PROB, LS.AC.PROB, LS.MAX.SEEN.AC, LS.CRUISE.SEEN.AC, LS.SLOW.SEEN.AC, LS.MAX.SEER.AC, LS.CRUISE.SEER.AC, LS.SLOW.SEER.AC, LS.AC.UPDATE.INTERVAL, LS.LOW.LATE, LS.HIGH.LATE, LS.X, LS.Y, LS.SLOPE, LS.CV.DIST, LS.SCBD.TIME, LS.SCBD.X, LS.SCBD.Y, LS.SCBD.SLOPE, LS.NEXT.WAY.PT, LS.NEXT.DETECTION, LS.NEXT.LOSE.CONTACT, LS.NEXT.PENETRATION and LS.NEXT.LAUNCH.IW
as double variables

define LS.IN.PLAY, LS.CLASS, LS.HULL.NO, LS.MAX.SPEED, LS.CRUISE.SPEED, LS.SLOW.SPEED, LS.AC.DETECT.RANGE, LS.PATH.RECORD, LS.PATH.LEG, LS.SPEED, LS.MAX.WEAPON, LS.BUSY, LS.SEES.CV.AC, LS.SCBD.SPEED, LS.REMOVE and LS.LAST.PEN.ZONE
as integer variables

every RC
has a RC.IN.PLAY
and a RC.CLASS
and a RC.HULL.NO
and a RC.MAX.SPEED
and a RC.WRAP.TIME
and a RC.START.TIME
and a RC.START.HIGH
and a RC.START.LOW
and a RC.LOW.LATE
and a RC.HIGH.LATE
and a RC.EM.DETECT.RANGE
and a RC.AC.DETECT.RANGE
and a RC.EM.UPDATE.INTERVAL
and a RC.AC.UPDATE.INTERVAL
and a RC.PATH.RECORD
and a RC.PATH.LEG
and a RC.X
and a RC.Y
and a RC.SLOPE
and a RC.SPEED
and a RC.CV.DIST
and a RC.LS.DIST
and a RC.TIME.OF.LAST.EVAL
and a RC.INTERVAL
and a RC.SEES.CV.EM
and a RC.BUSY
and a RC.NEXT.WAY.PT
and a RC.NEXT.DETECTION
and a RC.NEXT.LOSE.CONTACT
and a RC.NEXT.PENETRATION
and a RC.LAST.PEN.ZONE
and a RC.REMOVE
and may belong to a 1RCAC
and may belong to a 1RCEM
and may belong to a 2RCEM

define RC.WRAP.TIME, RC.START.TIME, RC.START.HIGH, RC.START.LOW, RC.LOW.LATE, RC.HIGH.LATE, RC.EM.DETECT.RANGE, RC.AC.DETECT.RANGE, RC.EM.UPDATE.INTERVAL, RC.AC.UPDATE.INTERVAL, RC.X, RC.Y, RC.SLOPE, RC.CV.DIST, RC.LS.DIST, RC.TIME.OF.LAST.EVAL, RC.INTERVAL, RC.NEXT.WAY.PT, RC.NEXT.DETECTION, RC.NEXT.LOSE.CONTACT and RC.NEXT.PENETRATION
as double variables

define RC.IN.PLAY, RC.CLASS, RC.HULL.NO, RC.MAX.SPEED, RC.PATH.RECORD, RC.PATH.LEG, RC.SPEED, RC.SEES.CV.EM, RC.BUSY, RC.REMOVE and RC.LAST.PEN.ZONE
as integer variables

every IW
has an IW.CLASS
and an IW.HULL.NO
and an IW.READY.TIME
and an IW.MAX.SPEED
and an IW.RANGE
and an IW.RLERR
and an IW.DHT.PT
and an IW.DHT.RADIUS
and an IW.NHT.PT
and an IW.NHT.RADIUS
and an IW.LETHALITY

define IW.READY.TIME, IW.RANGE, IW.RLERR, IW.DHT.RADIUS and IW.NHT.RADIUS
as double variables

define IW.CLASS, IW.HULL.NO, IW.MAX.SPEED, IW.DHT.PT, IW.NHT.PT and IW.LETHALITY
as integer variables

```
        temporary entities

      every IBW
            has an IBW.CLASS
            has an IBW.HULL.NO
            and an IBW.X
            and an IBW.Y
            and an IBW.SLOPE
            and an IBW.SPEED
            and an IBW.TIME.OF.LAST.EVAL
            and an IBW.INTERVAL
            and an IBW.REMOVE
            and an IBW.HIT.TIME
            and an IBW.BUSY
            and an IBW.NEXT.PENETRATION
            and an IBW.LAST.PEN.ZONE

  define IBW.X, IBW.Y, IBW.SLOPE, IBW.HIT.TIME,
         IBW.TIME.OF.LAST.EVAL, IBW.NEXT.PENETRATION, and
         IBW.INTERVAL
           as double variables

  define IBW.CLASS, IBW.HULL.NO, IBW.SPEED, IBW.REMOVE, IBW.BUSY
         and IBW.LAST.PEN.ZONE
           as integer variables

"SYSTEM ORIENTED STATEMENTS

"       SETS CORRESPOND TO THE FOLLOWING OPPOSING SIDES:
"         CV,P3C,USSAT - 1        LS,BEAR,CPSAT - 2

  the system
     owns the 1RCEM
      and the 1RCAC
      and the 2RCEM
      and the 2LSAC

  define 1RCEM as a set ranked by low RC.LS.DIST
  define 1RCAC as a set ranked by low RC.LS.DIST
  define 2RCEM as a set ranked by low RC.CV.DIST
  define 2LSAC as a set ranked by low LS.CV.DIST
```

```
define RDN as a double variable

 define  EVAL.INTERVAL, TIME.OF.LAST.EVAL, PREF.RANGE,
            Z1R1, Z2R1, Z3R1, Z4R1, Z5R1,
            Z1R2, Z2R2, Z3R2, Z4R2, Z5R2,
            Z1R3, Z2R3, Z3R3, Z4R3, Z5R3,
            Z1R4, Z2R4, Z3R4, Z4R4, Z5R4,
            Z1R5, Z2R5, Z3R5, Z4R5, Z5R5,
            Z1R6, Z2R6, Z3R6, Z4R6, Z5R6,
            Z1R7, Z2R7, Z3R7, Z4R7, Z5R7,
            Z1R8, Z2R8, Z3R8, Z4R8, Z5R8,
            Z1R9, Z2R9, Z3R9, Z4R9, Z5R9,
            Z1R10, Z2R10, Z3R10, Z4R10, Z5R10,
            Z1R11, Z2R11, Z3R11, Z4R11, Z5R11,
            Z1R12, Z2R12, Z3R12, Z4R12, Z5R12,
            CAT1.REACT, CAT2.REACT, CAT3.REACT, CAT4.REACT,
            CAT5.REACT, CAT1.BUSY, CAT2.BUSY, CAT3.BUSY,
            CAT4.BUSY, CAT5.BUSY, BSY1, BSY2, BSY3, BSY4,
            BSY5, BSY6, BSY7, BSY8, BSY9, BSY10,
            PTS1, PTS2, PTS3, PTS4, PTS5,
            PTS6, PTS7, PTS8, PTS9 and PTS10
               as double variables

      define SOSUS,
      NO.REPLICATIONS, NO.RUN, NO.CV.WIN, NO.CV.LOSE,
      NO.21A, NO.19, NO.15, NO.650.TORP, NO.533.TORP,
      LS.HULL.PEN, BEAR.HULL.PEN,
      WEAP.CLASS.PEN, WEAP.HULL.PEN,
      SRV.CLASS, SRV.HULLNO and SRV.ZONE
         as integer variables

      define EVPOINTER as a pointer variable

      define RAD12 as a double function
      define RAD1 as a double function
      define RAD2 as a double function
      define RAD3 as a double function
      define RAD4 as a double function
      define RAD5 as a double function
      define RAD6 as a double function
      define RAD7 as a double function
      define RAD8 as a double function
      define RAD9 as a double function
      define RAD10 as a double function
```

```
        define RAD11 as a double function

        define DIST as a double function

        define SLOPE as a double function

        define .HOURS to mean units


"CV ZONES & PATH

        define CV1 as a 2-dimensional, double array
        define PIMX as a 2-dimensional, double array
        define PIMY as a 2-dimensional, double array

"LS PATH, SURVIVE.MAX, SURVIVE.CRUISE, SURVIVE.SLOW,
"       WEAPONS & ROF

"OSCAR
        define LS1 as a 2-dimensional, double array
        define LS2 as a 2-dimensional, double array
"SIERR
        define LS3 as a 2-dimensional, double array
        define LS4 as a 2-dimensional, double array
"AKULA
        define LS5 as a 2-dimensional, double array
        define LS6 as a 2-dimensional, double array
"KILO
        define LS7 as a 2-dimensional, double array
        define LS8 as a 2-dimensional, double array
        define LS9 as a 2-dimensional, double array
        define LS10 as a 2-dimensional, double array

"RC PATH, SURVIVE, SEES.EM.LS & SEES.AC.LS

"P3CU4
        define RC1 as a 2-dimensional, double array
        define RC2 as a 2-dimensional, double array
        define RC3 as a 2-dimensional, double array
        define RC4 as a 2-dimensional, double array
        define RC5 as a 2-dimensional, double array
"USSAT
        define RC6 as a 2-dimensional, double array
        define RC7 as a 2-dimensional, double array
```

```
        define RC8 as a 2-dimensional, double array
        define RC9 as a 2-dimensional, double array
        define RC10 as a 2-dimensional, double array
"BEAR
        define RC11 as a 2-dimensional, double array
        define RC12 as a 2-dimensional, double array
        define RC13 as a 2-dimensional, double array
        define RC14 as a 2-dimensional, double array
        define RC15 as a 2-dimensional, double array
"CPSAT
        define RC16 as a 2-dimensional, double array
        define RC17 as a 2-dimensional, double array
        define RC18 as a 2-dimensional, double array
        define RC19 as a 2-dimensional, double array
        define RC20 as a 2-dimensional, double array

"IW SURVIVE PER WEAPON TYPE

        define IW1 as a 1-dimensional, double array
        define IW2 as a 1-dimensional, double array
        define IW3 as a 1-dimensional, double array
        define IW4 as a 1-dimensional, double array
        define IW5 as a 1-dimensional, double array

"ARRAYS PER WEAPON TYPE FOR TEMPORARY ENTITIES IBWs

        define 1IW as a 1-dimensional, integer array
        define 2IW as a 1-dimensional, integer array
        define 3IW as a 1-dimensional, integer array
        define 4IW as a 1-dimensional, integer array
        define 5IW as a 1-dimensional, integer array

end
```

APPENDIX B. ASW SCREENING MODEL INPUT SAMPLES

The following examples are those input files used in the DEBUGGING and verification procedures. Many attributes and probabilities were set to arbitrary values, or to one, so that the flow of events could be examined for successful execution. These preliminary selected inputs are exactly those parameters considered to make a difference in the behavior of the real system under study. For each of the five separate input files, these attributes are named and listed in the order in which they are read by the simulation. The listing of these attribute names is followed by a table of actual values and format used for the model program code(The SIMSCRIPT II.5 input file methodology is reminiscent of the card-type environment of Fortran.). No discussion of this data is presented. Although what is shown has been slightly annotated so as to be somewhat self-explanatory. Titles of files used are for exposition only. File names are listed in acompanying parentheses.

1. Global Variables(MODEL.DAT)

```
SOSUS,              "SET#1 MAY KNOW SET#2 POSITIONS
NO.REPLICATIONS,    "STATISTICAL PRECISION
PREF.RANGE,         "WEAPON FIRING RULE'S
CAT1.REACT,         "CATEGORIZATION OF TIME TO REACT
CAT2.REACT,         "TO INBOUND WEAPONS...
CAT3.REACT,         "5 LEVELS OF CRITICALITY
```

```
CAT4.REACT,
CAT5.REACT,
CAT1.BUSY,      "BUSY POINTS ASSESSED PER ABOVE
CAT2.BUSY,      "CATEGORIES
CAT3.BUSY,
CAT4.BUSY,
CAT5.BUSY,
BSY1,           "PROBABILITIES OF COUNTERING
BSY2,           "INBOUND WEAPONS BASED ON
BSY3,           "STATE OF ATTENTION SPAN
BSY4,           "SATURATION
BSY5,
BSY6,
BSY7,
BSY8,
BSY9,
BSY10,
PTS1,           "PROBABILITIES OF COUNTERING
PTS2,           "INBOUND WEAPONS BASED ON
PTS3,           "BATTLE DAMAGE
PTS4,
PTS5,
```

PTS6,

PTS7,

PTS8,

PTS9,

PTS10

1 002 1.00

03 05 07 10 10

05 04 03 02 01

0.05 0.10 0.25 0.50 0.75 0.85

0.90 0.95 0.97 0.99 0.05 0.10

0.25 0.50 0.65 0.75 0.85 0.90

0.95 0.99

2. CARRIER DATA(CV.DAT)

CV.IN.PLAY(1),	"YES or NO
CV.CLASS(1),	"100
CV.HULL.NO(1),	"1
CV.DEST.X(1),	"X COORDINATE DESTINATION
CV.DEST.Y(1),	"Y COORDINATE DESTINATION
CV.SOA(1),	"HOURS ALLOWED TO GET THERE
CV.UNREP.TAG(1,	"YES or NO
CV.UNREP.INTERVAL(1),	"TIME BETWEEN

```
   CV.UNREP.PERIOD(1),          "TIME DURING
   CV.LAST.SPEED(1),            "SPEED TO RESUME AFTER UNREP
   CV.MAX.SPEED(1),             "KNOTS
   CV.CRUISE.SPEED(1),          "KNOTS
   CV.SLOW.SPEED(1),            "KNOTS
   CV.MAX.SEEN.AC(1),           "PROB OF BEING SEEN
   CV.CRUISE.SEEN.AC(1),        "PROB OF BEING SEEN
   CV.SLOW.SEEN.AC(1),          "PROB OF BEING SEEN
   CV.EM.PROB(1),               "PROBABILITY EMITTING RF
   CV.BUSY(1),                  "ATTENTION SPAN SATURATION
   CV.POINTS(1),                "BATTLE DAMAGE OR ENDURANCE
   CV.X(1),                     "STARTING POSITION
   CV.Y(1),                     "STARTING POSITION
   CV.PATH.LEG(1)               "WAY POINT LEG OF INITIAL PIM
"EXTREME POINTS OF RADII PER ZONE
ZONE 1     ZONE 2     ZONE 3     ZONE 4     ZONE 5
Z1R1       Z2R1       Z3R1       Z4R1       Z5R1
Z1R2       Z2R2       Z3R2       Z4R2       Z5R2
Z1R3       Z2R3       Z3R3       Z4R3       Z5R3
Z1R4       Z2R4       Z3R4       Z4R4       Z5R4
Z1R5       Z2R5       Z3R5       Z4R5       Z5R5
Z1R6       Z2R6       Z3R6       Z4R6       Z5R6
```

Z1R7 Z2R7 Z3R7 Z4R7 Z5R7

Z1R8 Z2R8 Z3R8 Z4R8 Z5R8

Z1R9 Z2R9 Z3R9 Z4R9 Z5R9

Z1R10 Z2R10 Z3R10 Z4R10 Z5R10

Z1R11 Z2R11 Z3R11 Z4R11 Z5R11

Z1R12 Z2R12 Z3R12 Z4R12 Z5R12

1 100 001 999.000 999.000 120.00

0 048 012 000

025 015 005

1.00 1.00 1.00 1.0 100 1000

000.000 000.000 050

001 001 001 001 001 001

001 001 001 001 001 001

007 007 007 007 007 007

007 007 007 007 007 007

025 025 025 025 025 025

025 025 025 025 025 025

250 250 025 025 025 025

025 025 025 250 250 250

350 350 050 050 050 050

050 050 050 350 350 350

3. SUBMARINE DATA(LS.DAT)

LS.IN.PLAY(A),	"YES or NO
LS.CLASS(A),	"LS
LS.HULL.NO(A),	"1
LS.MAX.SPEED(A),	"KNOTS
LS.CRUISE.SPEED(A),	"KNOTS
LS.SLOW.SPEED(A),	"KNOTS
LS.EM.PROB(A),	"PROBABILITY EMITTING RF
LS.AC.PROB(A),	"PROBABILITY DETECT BY SONAR
LS.MAX.SEEN.AC(A),	"PROB OF BEING SEEN
LS.CRUISE.SEEN.AC(A),	"PROB OF BEING SEEN
LS.SLOW.SEEN.AC(A),	"PROB OF BEING SEEN
LS.MAX.SEER.AC(A),	"PROB OF SEEING
LS.CRUISE.SEER.AC(A),	"PROB OF SEEING
LS.SLOW.SEER.AC(A),	"PROB OF SEEING
LS.AC.DETECT.RANGE(A),	"RANGE ACOUSTIC SENSOR
LS.AC.UPDATE.INTERVAL(A),	"TRACKING UPDATE
LS.LOW.LATE(A),	"LOWER BOUND ON INFO LATE
LS.HIGH.LATE(A),	"UPPER BOUND ON INFO LATE
LS.X(A),	"STARTING POSITION
LS.Y(A),	"STARTING POSITION
LS.PATH.LEG(A)	"WAY POINT LEG LENGTH

```
LS1(2,B),                    "MAX.SPEED SURVIVE PER ZONE
LS1(3,B),                    "CRUISE.SPEED SURVIVE PER ZONE
LS1(4,B)                     "SLOW.SPEED SURVIVE PER ZONE
LS1(5,1),                    "# SS-N-21A
LS1(5,2),                    "# SS-N-19
LS1(5,3),                    "# SS-N-15
LS1(5,4),                    "# TORP-650MM
LS1(5,5),                    "# TORP-533MM
LS1(6,1),                    "RATE OF FIRE SS-N-21A
LS1(6,2),                    "RATE OF FIRE SS-N-19
LS1(6,3),                    "RATE OF FIRE SS-N-15
LS1(6,4),                    "RATE OF FIRE TORP-650MM
LS1(6,5),                    "RATE OF FIRE TORP-533MM

1       200     01      025     015     005
1.00    1.00
1.00    1.00    1.00    1.00    1.00    1.00
250     1.00    001.0   006.0
100.000 300.000 100
000.00  000.00  000.00
999.00  999.00  999.00
999.00  999.00  999.00
```

002.00 006.00 999.00

999.00 999.00 999.00

00.0 24.0 08.0 18.0 00.0

00.0 04.0 04.0 06.0 00.0

4. RECONNAISANCE DATA(RC.DAT)

RC.IN.PLAY(A), "YES or NO

RC.CLASS(A), "RC

RC.HULL.NO(A), "1

RC.MAX.SPEED(A), "KNOTS

RC.WRAP.TIME(A), "ORBIT IN MINUTES

RC.START.TIME(A), "ENTER GAME BOARD

RC.LOW.LATE(A), "LOWER BOUND ON INFO LATE

RC.HIGH.LATE(A), "UPPER BOUND ON INFO LATE

RC.EM.DETECT.RANGE(A), "RANGE OF EM SENSOR

RC.AC.DETECT.RANGE(A), "RANGE OF AC SENSOR

RC.EM.UPDATE.INTERVAL(A),"TRACKING UPDATE

RC.AC.UPDATE.INTERVAL(A),"TRACKING UPDATE

RC.PATH.LEG(A), "WAY POINT LEG LENGTH

RC.START.HIGH(A), "UPPER BOUND ON START POS.

RC.START.LOW(A), "LOWER BOUND ON START POS.

RC1(2,1), "PROBABILITY SURVIVE PER ZONE

RC1(2,2),

RC1(2,3),

RC1(2,4),

RC1(2,5)

AIRCRAFT

1 300 01 240 000.0 024.0

001.0 002.0 500 250 1.00 1.00

150 000.000 000.000

999.00 999.00 999.00 999.00 999.00

SATELLITE

1 300 06 500 000.0 006.0

001.0 002.0 999 000 1.00 1.00

999.00 999.00 999.00 999.00 999.00

000.000

400.000

300.000

999.000

5. WEAPON DATA(IW.DAT)

IW.CLASS(A), "1-5 PER TYPE

IW.HULL.NO(A), "IDENTITY

IW.READY.TIME(A), "PREPARATION TIME BETWEEN VOLLEYS

```
   IW.MAX.SPEED(A),          "ONLY ONE SPEED
   IW.RANGE(A),              "MAXIMUM RANGE
   IW.RLERR(A),              "RELIABILITY ERROR
   IW.DHT.PT(A),             "DIRECT HIT POINTS
   IW.DHT.RADIUS(A),         "DIRECT HIT POINT RADIUS
   IW.NHT.PT(A),             "NEAR HIT POINTS
   IW.NHT.RADIUS(A),         "NEAR HIT POINT RADIUS
   IW.LETHALITY(A),          "GRID NODE WEIGHT
   IW1(1),                   "PROBABILITY SURVIVE PER ZONE
   IW1(2),
   IW1(3),
   IW1(4),
   IW1(5)
SS-N-21A( other four types not shown)
1       000       0.25      350       0999      0.00
150     025       040       050       015
000.00  000.03    000.06    999.00    000.16
```

APPENDIX C. ASW SCREENING MODEL OUTPUT SAMPLES

The following examples are taken from a version of the model which does not include the routine that defends against inbound missiles(See Chapter V Section B, 1 & 2). Therefore, the scenario described by the output provided has all missiles successfully launch and penetrate without resistance. Further, DEBUGGING and verification procedures were in use in this instance such that all Monte Carlo probabilities were set to one throughout the model so that the flow of events could be examined for successful execution. These preliminary selected outputs are shown to give the reader a sense of the model's potential behavior despite its incomplete state. The data written to the output file for each event is only that which was of interest to the author and is merely a subset of that available. No discussion of this data is presented, although what is shown has been slightly annotated so as to be somewhat self-explanatory. Titles of events correspond to those used in the body of this report. Those in acompanying parentheses are actual names used in the program code.

1. Broadcast to Network (LS_INFO_TO_CV)

LS_INFO_TO_CV at time .0010 SOSUS = 1

EVALUATE at time .001000

Current Positions:

CV(1)	X =	.011	Y =	.011
LS = 1	X =	100.002	Y =	299.996
LS = 2	X =	300.002	Y =	99.996
LS = 3	X =	50.002	Y =	399.996
LS = 4	X =	150.002	Y =	399.996
LS = 5	X =	400.002	Y =	149.996
LS = 6	X =	400.002	Y =	49.996
LS = 7	X =	50.002	Y =	199.996
LS = 8	X =	150.002	Y =	199.996
LS = 9	X =	200.002	Y =	149.996
LS = 10	X =	200.002	Y =	49.996

SHORTEST PATHS = 3 RANDOM SELECT # = 2 ACTUAL PIM = 251

PIM WAY POINTS in terms of X and Y coordinates:

CV1(6,1) =	.011	CV1(6,2) =	199.808
CV1(6,3) =	.011	CV1(6,4) =	399.606
CV1(6,5) =	.011	CV1(6,6) =	599.404
CV1(6,7) =	.011	CV1(6,8) =	799.202
CV1(6,9) =	199.808	CV1(6,10) =	799.202
CV1(6,11) =	199.808	CV1(6,12) =	999.000
CV1(6,13) =	399.606	CV1(6,14) =	999.000
CV1(6,15) =	599.404	CV1(6,16) =	999.000
CV1(6,17) =	799.202	CV1(6,18) =	999.000

2. Penetration of Carrier Zone (LS_PENETRATE)

LS_PENETRATE at time 5.3825 HULLNO = 1 ZONE = 4

EVALUATE at time 5.382539

Current Positions:

CV(1)	X =	1.356	Y =	134.542
LS = 1	X =	27.172	Y =	276.849
LS = 2	X =	235.733	Y =	139.555
LS = 3	X =	57.674	Y =	408.030
LS = 4	X =	90.349	Y =	298.164
LS = 5	X =	310.180	Y =	145.707
LS = 6	X =	311.709	Y =	65.903
LS = 7	X =	22.109	Y =	165.202
LS = 8	X =	104.590	Y =	176.109
LS = 9	X =	147.936	Y =	177.086
LS =10	X =	156.686	Y =	88.570
RC =16	X =	309.454	Y =	818.135

3. Detection of Opposition(LS_DETECTION)

LS_DETECTION at time 7.0000

MODE = 2 SEER_HULLNO = 6 SEEN_HULLNO = 7

EVALUATE at time 7.000000

Current Positions:

CV(1)	X =	1.760	Y =	174.977
LS = 1	X =	8.199	Y =	241.139
LS = 2	X =	199.689	Y =	157.884
LS = 3	X =	59.180	Y =	415.976
LS = 4	X =	66.323	Y =	246.905
LS = 5	X =	261.965	Y =	140.238
LS = 6	X =	263.722	Y =	73.101
LS = 7	X =	11.092	Y =	134.787
LS = 8	X =	82.887	Y =	152.120
LS = 9	X =	116.247	Y =	183.593
LS =10	X =	130.445	Y =	107.489
RC = 6	X =	223.905	Y =	847.064

4. Broadcast to Network(CV_INFO_TO_LS)

CV_INFO_TO_LS at time 7.2714

SCORE BOARD INFO ON CV:

TIME CV SEEN was 6.2714

X was 1.578 Y was 156.764

COURSE was 100.00 SPEED was 25

EVALUATE at time 7.271439

Current Positions:

CV(1)	X =	1.828	Y =	181.762
LS = 1	X =	5.015	Y =	235.146
LS = 2	X =	193.641	Y =	160.960
LS = 3	X =	59.432	Y =	417.309
LS = 4	X =	62.291	Y =	238.302
LS = 5	X =	253.874	Y =	139.320
LS = 6	X =	255.669	Y =	74.308
LS = 7	X =	10.301	Y =	129.445
LS = 8	X =	79.245	Y =	148.095
LS = 9	X =	110.930	Y =	184.685
LS =10	X =	126.042	Y =	110.664
RC = 6	X =	284.682	Y =	968.415

5. Contact Loss on Opposition (LS_LOSE_CONTACT)

LS_LOSE_CONTACT at time 7.6856 MODE = 2

SEER_HULLNO = 6 SEEN_HULLNO = 1

EVALUATE at time 7.685619

Current Positions:

CV(1)	X =	1.932	Y =	192.116
LS = 1	X =	.157	Y =	226.002
LS = 2	X =	184.411	Y =	165.654
LS = 3	X =	59.818	Y =	419.344
LS = 4	X =	53.600	Y =	226.700
LS = 5	X =	241.494	Y =	140.380
LS = 6	X =	243.938	Y =	78.404
LS = 7	X =	9.511	Y =	121.199
LS = 8	X =	73.687	Y =	141.952
LS = 9	X =	103.211	Y =	181.678
LS =10	X =	118.524	Y =	114.142

6. Course & Speed Changes (CV_WAY_PT)

CV_WAY_PT at time 7.9933

FROM TIME = 7.9929 FROM PLACE = CV_WAY_PT

EVALUATE at time 7.993315

Current Positions:

CV(1)	X =	2.009	Y =	199.808
LS = 1	X =	-3.452	Y =	219.209
LS = 2	X =	177.554	Y =	169.141
LS = 3	X =	60.105	Y =	420.856
LS = 4	X =	47.144	Y =	218.080
LS = 5	X =	232.297	Y =	141.168
LS = 6	X =	235.223	Y =	81.447
LS = 7	X =	8.925	Y =	115.073
LS = 8	X =	69.558	Y =	137.389
LS = 9	X =	97.476	Y =	179.445
LS =10	X =	112.939	Y =	116.726

7. Arrival of Reconnaissance (RC_START)

RC_START at time 9.0000 HULL.NO = 17

EVALUATE at time 9.000000

Current Positions:

CV(1)	X =	2.260	Y =	224.974
LS = 1	X =	-15.260	Y =	196.984
LS = 2	X =	155.121	Y =	180.549
LS = 3	X =	61.042	Y =	425.801
LS = 4	X =	26.021	Y =	189.880
LS = 5	X =	202.207	Y =	143.746
LS = 6	X =	206.710	Y =	91.401
LS = 7	X =	7.005	Y =	95.031
LS = 8	X =	56.051	Y =	122.459
LS = 9	X =	78.715	Y =	172.138
LS =10	X =	94.666	Y =	125.180
RC =17	X =	100.000	Y =	0.

8. Submarine Weapon Launch (LS_LAUNCH_IW)

LS_LAUNCH_IW at time 9.4498 IW TYPE = 1 LS HULLNO = 4

CV.SCBD.X = 1.578 CV.SCBD.Y = 156.764

EVALUATE at time 9.449834

Current Positions:

CV(1)	X =	2.373	Y =	236.220
LS = 1	X =	-20.537	Y =	187.053
LS = 2	X =	145.097	Y =	185.646
LS = 3	X =	61.461	Y =	428.011
LS = 4	X =	16.583	Y =	177.279
LS = 5	X =	188.761	Y =	144.898
LS = 6	X =	193.970	Y =	95.850
LS = 7	X =	6.148	Y =	86.075
LS = 8	X =	50.015	Y =	115.787
LS = 9	X =	70.332	Y =	168.873
LS =10	X =	86.501	Y =	128.958
RC =17	X =	200.666	Y =	201.131

4 no.21A's fired from LS 4 ... call missile.pen.next

PROJECTED HIT TIME at 12.3041

TARGETX = 2.292 TARGETY = 228.117

9. Removal of Opposition Object (REMOVE)

REMOVE at time 9.6407

CLASS = 1 HULLNO = 4

FROM TIME = 9.4498 FROM PLACE = LAUNCH_IW

CV.POINTS(1) at entry to this event = 30

EVALUATE at time 9.640717

Current Positions:

CV(1)	X =	2.420	Y =	240.991
LS = 1	X =	-22.776	Y =	182.839
LS = 2	X =	140.843	Y =	187.810
LS = 3	X =	61.639	Y =	428.949
LS = 4	X =	12.578	Y =	171.931
LS = 5	X =	183.055	Y =	145.387
LS = 6	X =	188.563	Y =	97.737
LS = 7	X =	5.784	Y =	82.275
LS = 8	X =	47.453	Y =	112.956
LS = 9	X =	66.775	Y =	167.488
LS =10	X =	83.036	Y =	130.561
RC =17	X =	243.383	Y =	286.480
SS-N-21A = 4	X =	-1.497	Y =	241.595

PROXIMITY distance to carrier = 3.9635834219

CV.POINTS(1) as a result of this event = -120

(Note: Direct Hit Point Value of SS-N-21A = 150)

10. Replication End & Summary Statistics (STATS & REPORT)

FROM STATS(only carrier's listing is shown)

ATTRIBUTES OF EACH CV

CV.IN.PLAY	=	1
CV.CLASS	=	100
CV.HULL.NO	=	1
CV.DEST.X	=	999.0000000000
CV.DEST.Y	=	999.0000000000
CV.SOA	=	120.0000000000
CV.UNREP.TAG	=	0
CV.UNREP.INTERVAL	=	48.0000000000
CV.UNREP.PERIOD	=	12.0000000000
CV.LAST.SPEED	=	0
CV.MAX.SPEED	=	25
CV.CRUISE.SPEED	=	15
CV.SLOW.SPEED	=	5
CV.MAX.SEEN.AC	=	1.0000000000
CV.CRUISE.SEEN.AC	=	1.0000000000

CV.SLOW.SEEN.AC = 1.0000000000
CV.EM.PROB = 1.0000000000
CV.BUSY = 95
CV.POINTS = -120
CV.X = 2.4204153496
CV.Y = 240.9914813884
CV.SEES.LS = 1
CV.PATH.RECORD = 0
CV.PATH.LEG = 50
CV.SLOPE = 100.0000000000
CV.SPEED = 25
CV.STOP.TIME = 9.6407169412
CV.SCBD.TIME = 6.2714385216
CV.SCBD.X = 1.5781378575
CV.SCBD.Y = 156.7637321816
CV.SCBD.SLOPE = 100.0000000000
CV.SCBD.SPEED = 25
CV.NEXT.WAY.PT = 15.9759179470
CV.NEXT.UNREP = 48.0000000000

FROM REPORT(only 1 replication was run)
NO.CV.WIN = 0
NO.CV.LOSE = 1

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